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Final Report, Phase I

July 1975

MEASURING SNOW COVER USING SATELLITE IMAGERY DURING 1973 AND 1974 MELT SEASON: NORTH SANTIAM, BOISE, AND UPPER SNAKE BASINS

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CORPS OF ENGINEERS, NORTH PACIFIC DIVISION
(Funded by National Aeronautics and Space Administration)
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SRI Project 4122

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ABSTRACT

Measurements of snow coverage during the snow-melt season in 1973 and 1974 were gathered from LANDSAT imagery for the following Columbia River Subbasins:

- North Santiam Basin (above Detroit Dam), Oregon
- Boise Basin (above Lucky Peak), Idaho
- Upper Snake River Basin (above Palisades Dam), Wyoming.

The principal objective of the program was to provide satellite-derived snow cover inventories for the three test basins for use by the Bonneville Power Administration as an alternative to inventories performed with the current operational practice of using small aircraft flights over selected snow fields. A secondary objective was to continue investigating accuracy and precision versus cost for several different interactive image analysis procedures currently under study at SRI, using the SRI Electronic Satellite Image Analysis Console (ESIAC). The research was completed under Contract 53442, sponsored jointly by the Bonneville Power Administration and the Corps of Engineers, North Pacific Division, under funding by the National Aeronautics and Space Administration.

Single-band radiance thresholding was the principal technique employed in the snow detection, although this technique was supplemented by an editing procedure involving reference to hand-generated elevation contours. For each date and view measured, a binary thematic map or "mask" depicting the snow cover was generated by a combination of objective and subjective procedures. Each mask was documented through three different methods:

- Photography.
- A numerical pixel count representative of the total area of snow in the scene and within the basin boundary.
- An array of single digit numbers depicting tenths of snow cover for each 2.5 X 2.5 km cell within the basin.

The cell-by-cell numeric documentation procedure provides a convenient and effective means of comparing the ESIAC-derived results with findings obtained by more conventional photointerpretation or with ground or aircraft surveys. More important, the cell-by-cell machine documentation paves the way for the use of advanced basin modeling procedures--for example, those requiring that snowpack be inventoried in elevation increments.

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I INTRODUCTION

This is the Final Report of Contract 53442 (SRI Project 4122-1) and is intended to fully comply with the requirements of that contract.

A Objectives

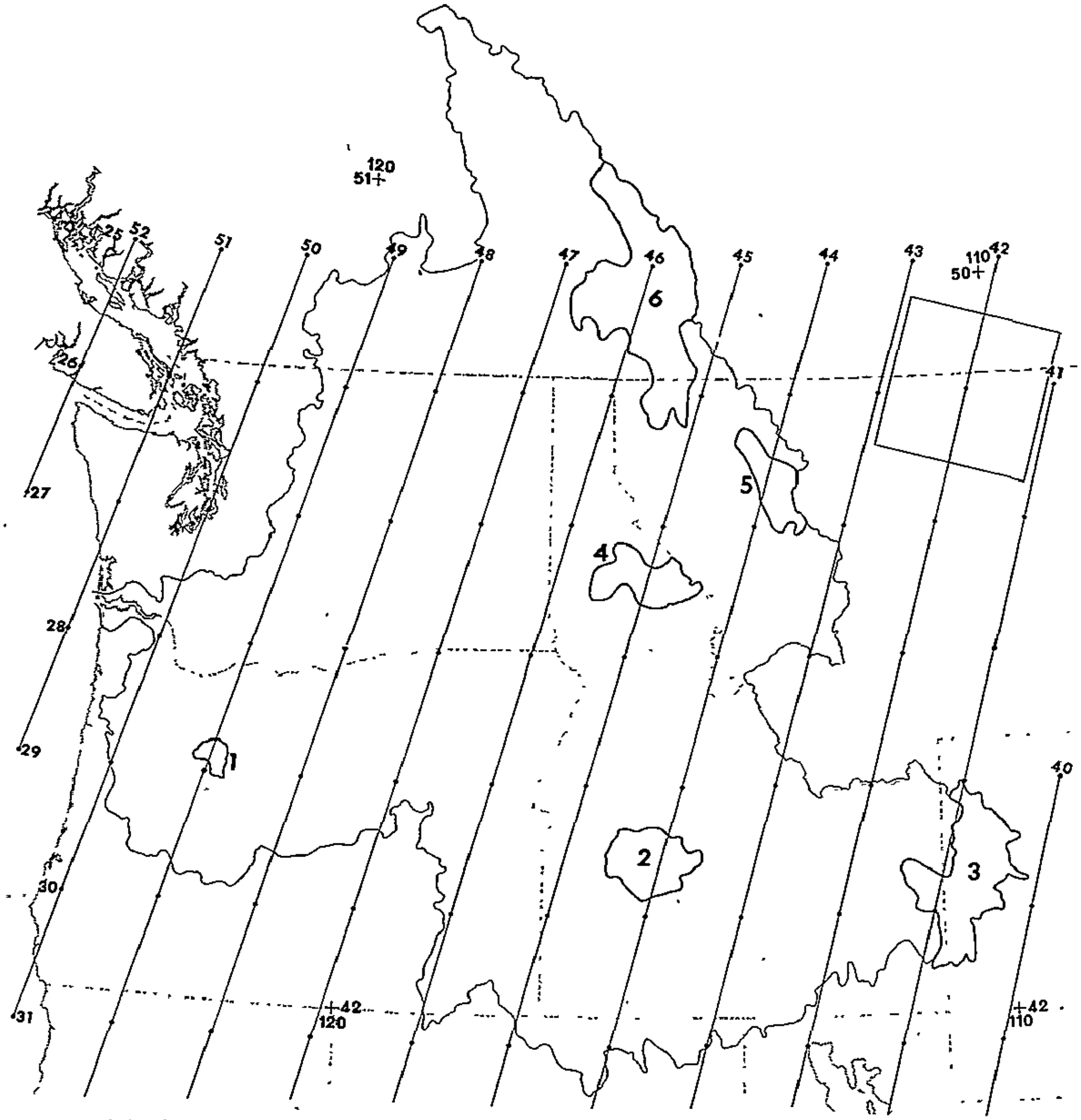
Measurements of snow coverage during the snow-melt season in 1973 and 1974 were gathered from LANDSAT imagery for the following Columbia River Subbasins:

- North Santiam Basin (above Detroit Dam), Oregon
- Boise Basin (above Lucky Peak), Idaho
- Upper Snake River Basin (above Palisades Dam), Wyoming.

The principal objective of the program was to provide satellite-derived snow cover inventories for the three test basins for use by the Bonneville Power Administration as an alternative to inventories performed with the current operational practice of using small aircraft flights over selected snow fields. A secondary objective was to continue investigating accuracy and precision versus cost for several different interactive image analysis procedures currently under study at SRI, using the SRI Electronic Satellite Image Analysis Console (ESIAC).

B Data

Satellite orbital and scene coverage over the Columbia River Basin is shown in Figure 1. Normally it takes one LANDSAT frame to view the North Santiam Basin, two frames for the Boise basin and two to four frames to cover the Upper Snake Basin, depending upon the actual daily orbital



Columbia River Subbasins:

1. North Santiam (Detroit)
2. Boise
3. Upper Snake
4. Dworshak
5. Hungry Horse
6. Libby

FIGURE 1 NOMINAL ORBITAL TRACKS AND FRAME CENTER LOCATIONS OVER THE COLUMBIA RIVER BASIN

position of the satellite. Specifically, the data periods investigated for the North Santiam Basin extended from January through June in 1973 and 1974; for the Boise Basin and Upper Snake Basin the periods extended from late March through June in both years.

The set of LANDSAT imagery available for measurement (and their utility to the project, and therefore reasons for selection) of the three basins are given in Tables 1, 2, and 3.

C Method of Approach

Snow coverage was inventoried using a program which combined objective classification by single-band (MSS-5) radiance thresholding with subjective editing guided by elevation contours and other reference data. The procedure involved the use of the SRI Electronic Satellite Image Analysis Console (ESIAC), which was designed specifically to analyze repetitive satellite data. (A detailed description of ESIAC appears in the Appendix.) LANDSAT imagery were entered into the ESIAC memory at a scale such that the TV screen covered about 55 x 40 km, corresponding approximately to 0.5° of longitude by 0.5° of latitude, essentially to match the display resolution to the resolution available from the LANDSAT imagery. At that magnification it requires eleven TV views to cover the largest basin, Upper Snake; four views to cover Boise, and one view for the smallest basin, North Santiam; each TV view was considered a basin part. In addition to the imagery, a binary basin outline map and Universal Transverse Mercator (UTM) grid in 2.5 x 2.5 km boxes were entered for each view. All components were spatially registered to each other during the data entry process.

Registered time-lapse sequences, in color, were created for each basin. These were used for operator training and to evaluate progressive date-to-date changes in the snowpacks.

Table 1

ANNOTATED LISTING OF LANDSAT IMAGERY VIEWING THE NORTH SANTIAM BASIN

Track Row	Cycle	Dates On Hand	Frame Number	Percent of Basin Viewed in Frame	Sun Angle	Cloud Coverage	Overall Picture Quality	Utility to Project
		<u>1973</u>						
49-29	9*	6 Jan.	1167 - 18271	100	Low	20%	Good	Fair--20% of basin fog-covered
49-29	11*	11 Feb.	1203 - 18274	100	Low	Nil	Good	Fair--deep shadows
49-29	14*	6 Apr.	1257 - 18280	100	Medium	Nil	Good	Good
49-29	15*	24 Apr.	1275 - 18275	100	Medium	Nil	Good	Good
49-29	16*	12 May	1293 - 18274	100	Medium	Nil	Good	Good
49-29	17	30 May	1311 - 18273	100	High	80%	Fair	Poor--too many clouds
		<u>1974</u>						
49-29	29*	1 Jan.	1527 - 18241	100	Low	Nil	Good	Fair--deep shadows
49-29	31*	6 Feb.	1563 - 18225	100	Low	Nil	Good	Fair--deep shadows
49-29	32*	24 Feb.	1581 - 18224	100	Low	10%	Good	Fair--some cloud obscurement
49-29	38*	12 Jun.	1689 - 18200	100	High	75%	Fair	Marginal--cloudy
49-29	39*	30 Jun.	1707 - 18192	100	High	Nil	Good	Good

*Dates used for evaluation.

Table 2

ANNOTATED LISTING OF LANDSAT IMAGERY AVAILABLE FOR THE BOISE BASIN

Track Row	Cycle	Dates On-Hand	Frame Number	Percent of Basin Viewed in Frame	Sun Angle	Cloud Coverage	Overall Picture Quality	Utility to Project
		1973						
44-30	10	19 Jan.	1180 - 17500	99	Low	Nil	Good	Good--top tip of basin
45-30	10	20 Jan.	1181 - 18044	30	Low	Nil	Good	Good not viewed
44-30	11	6 Feb.	1198 - 17592	--	Low	80%	Fair	Poor--too cloudy
44-29	11	6 Feb.	1198 - 17585	--	Low	80%	Fair	Poor--too cloudy
44-30	13	14 Mar.	1234 - 17594	70	Medium	Nil	Good	Good } 100% basin
44-29	13	14 Mar.	1234 - 17591	50	Medium	Nil	Good	Good } viewed
44-30	14	1 Apr.	1252 - 17594	80	Medium	10%	Good	Good--some clouds, 80% basin viewed
44-29	14	1 Apr.	1252 - 17591	55	Medium	70%	Fair	Poor--cloudy, 80% basin viewed
44-29	15*	19 Apr.	1270 - 17591	--	Medium	90%	Fair	Poor--too cloudy
44-30	15	19 Apr.	1270 - 17594	95	Medium	5%	Good	Good--95% of basin viewed
44-30	16*	7 May	1288 - 17593	100	High	10-15%	Good	Good } 100% basin
44-29	16	7 May	1288 - 17590	10	High	10%	Good	Good } viewed
44-30	18*	12 Jun.	1324 - 17591	90	High	40%	Good	Good } 100% basin
44-29	18	12 Jun.	1324 - 17584	25	High	40%	Good	Good } viewed
44-30	19*	30 Jun.	1342 - 17585	95	High	20%	Good	Good } 100% basin
44-29	19	30 Jun.	1342 - 17583	20	High	20%	Good	Good } viewed
		1974						
45-29	32	20 Feb.	1577 - 17594	20	Low	Nil	Good	Fair } deep shadows 35% basin
45-30	32	20 Feb.	1577 - 18001	25	Low	Nil	Good	Fair } viewed
44-29	33	9 Mar.	1594 - 17534	20	Low	Nil	Good	Good--deep shadows
44-30	33	9 Mar.	1594 - 17541	90	Low	Nil	Good	Good } 100% basin
45-30	33	10 Mar.	1595 - 17595	20	Low	10%	Good	Good } viewed
44-29	35*	14 Apr.	1630-- 17530	50	Medium	Nil	Good	Good } 100% basin
44-30	35	14 Apr.	1630 - 17532	70	Medium	Nil	Good	Good } viewed
44-29	36*	2 May	1648 - 17523	40	High	Nil	Good	Good--100% basin viewed
44-30	36	2 May	1648 - 17525	80	High	Nil	Good	Good--Band 5 missing
44-29	39*	25 Jun.	1702 - 17505	15	High	Nil	Good	Good } 100% basin
44-30	39	25 Jun.	1702 - 17512	95	High	Nil	Good	Good } viewed

*Dates used for evaluation. For this phase of the study, the beginning of the snow melt season was considered to be 1 April.

Table 3

ANNOTATED LISTING OF LANDSAT IMAGERY AVAILABLE FOR THE UPPER SNAKE BASIN

Track Row	Cycle	Dates On-Hand	Frame Number	Percent of Basin Viewed in Frame	Sun Angle	Cloud Coverage	Overall Picture Quality	Utility to Project Comments
		1973						
41-30	10	16 Jan.	1177 - 17413	10	Low	100%	Poor	Poor } 80% basin
42-30	10	17 Jan.	1178 - 17472	80	Low	10%	Good	Good } viewed
41-30	11	3 Feb.	1195 - 17414	96	Low	10%	Good	Good } 100% basin
41-30	11	3 Feb.	1195 - 17420	96	Low	10%	Good	Good } viewed
41-30	12	21 Feb.	1213 - 17422	90	Low	Nil	Good	Good } 97% basin
41-29	12	21 Feb.	1213 - 17415	90	Low	Nil	Good	Good } viewed
41-30	14*	29 Mar.	1249 - 17423	85	Medium	5%	Good	Good } 97% basin
41-29	14	29 Mar.	1249 - 17420	85	Medium	5%	Good	Good } viewed
41-29	15	16 Apr.	1267 - 17420	80	Medium	100%	Poor	Poor } too cloudy
41-30	15	16 Apr.	1267 - 17422	80	Medium	100%	Poor	Poor }
41-30	17*	22 May	1303 - 17421	80	High	Nil	Good	Good } 95% basin
41-29	17	22 May	1303 - 17414	80	High	Nil	Good	Good } viewed
41-30	18*	9 Jun.	1321 - 17415	80	High	15%	Good	Good } 95% basin
41-29	18	9 Jun.	1321 - 17413	80	High	15%	Good	Good } viewed
41-30	19*	27 Jun.	1339 - 17414	75	High	40%	Fair	Poor--clouds and marginal view
		1974						
41-29	36	29 Apr.	1645 - 17352	90	Medium	80%	Poor	Band 7 only--poor } too cloudy
41-30	36	29 Apr.	1645 - 17355	90	Medium	80%	Poor	Band 7 only--poor }
41-29	37	17 May	1663-- 17345	85	High	80%	Poor	Poor } too cloudy
41-30	37	17 May	1663 - 17352	85	High	80%	Poor	Poor }
41-30	39*	22 Jun.	1699 - 17341	90	High	10%	Good	Good } 97% basin
41-29	39	22 Jun.	1699 - 17335	90	High	10%	Good	Good } covered

*Dates used for evaluation. For this phase of the study, the beginning of the snow melt season was considered to be 1 April. Also, by prior agreement, dates prior to 15 March were excluded because the low sun angle makes interpretation extremely difficult and of doubtful utility.

For each date and view measured, a binary thematic map or "mask" depicting the snow cover was generated by a combination of objective and subjective procedures:

(1) Radiance thresholding of the MSS-5 image.

(2) Localized threshold adjustment to obtain an optimum visual match to the visually observed snow cover for various sub-regions within the scene.

(3) Use of superimposed elevation contours for guidance.

(4) Final manual editing of the mask when necessary.

Each mask was documented through three different methods:

(1) Photography.

(2) A numerical pixel count representative of the total area of snow in the scene and within the basin boundary.

(3) An array of single digit numbers depicting tenths of snow cover for each 2.5 x 2.5 km cell within the basin.

The cell-by-cell numeric documentation procedure is an innovation and was used for the first time in this project. In the near term it provides a convenient and effective comparison of the ESIAC-derived results with findings obtained by more conventional photointerpretation, or with ground or aircraft surveys. More important, the cell-by-cell machine documentation paves the way for the use of advanced basin modeling procedures--for example, those requiring that the snowpack be inventoried in elevation increments.

II SUMMARY OF MEASUREMENTS

A summary of the snow coverage for the three selected basins is presented in Tables 4, 5, and 6, and Figures 2, 3, and 4, respectively. The snow coverage reported in these summaries is listed by areal amount (km^2) and by relative coverage (percentage) with respect to the basin area measurable on the LANDSAT imagery provided SRI. The measurable basin area may not always equal the full area of the basin because of the presence of clouds in certain portions; nonnominal positioning of the LANDSAT imagery may also preclude measurement of certain limited regions. Fortunately, the total basin area was viewed for the North Santiam and Boise Basins on all days, and no less than 95 percent of the basin was viewed for the Upper Snake Basin on all days. Therefore, the snow coverage percentages derived for the Upper Snake Basin can be assumed to apply to the total basin area with reasonable confidence. For a more justifiable extrapolation, probable snow area for the missing regions could be estimated from the elevation of the missing regions and the date. Section IV B contains additional comments on this subject.

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Table 4

NORTH SANTIAM BASIN SNOW COVERAGE

Date	Percent of Basin Area Covered by Usable Imagery	Snow Coverage	
		Area (km^2)	Percent of Basin Area*
<u>1973</u>			
6 Jan.	100	858.4	74.9%
11 Feb.	100	891.6	77.8
6 Apr.	100	519.1	45.3
24 Apr.	100	475.6	41.5
12 May	100	205.1	17.9
<u>1974</u>			
1 Jan.	100	975.2	85.1
6 Feb.	100	1,002.8	87.5
24 Feb.	100	1,080.7	94.3
12 Jun.	100	405.7	35.4
30 Jun.	100	190.2	16.6

Average elevation ~ 3,900 ft MSL
Basin area = 1,146 km^2

*Measured snow area/viewable area.

Table 5

BOISE BASIN SNOW COVERAGE

Date	Percent of Basin Area Covered by Usable Imagery	Snow Coverage	
		Area (km^2)	Percent of Basin Area*
<u>1973</u>			
19 Apr.	100	4,750.4	65.5%
7 May	100	2,270.4	31.3
12 Jun.	100	594.0	8.2
30 Jun.	100	278.6	3.7
<u>1974</u>			
14 Apr.	100	5,377.0	74.1
2 May	100	2,609.5	36.0
25 Jun.	100	504.5	7.0

Average elevation ~ 6,000 ft MSL
Basin area = 7,254 km^2

*Measured snow area/viewable area.

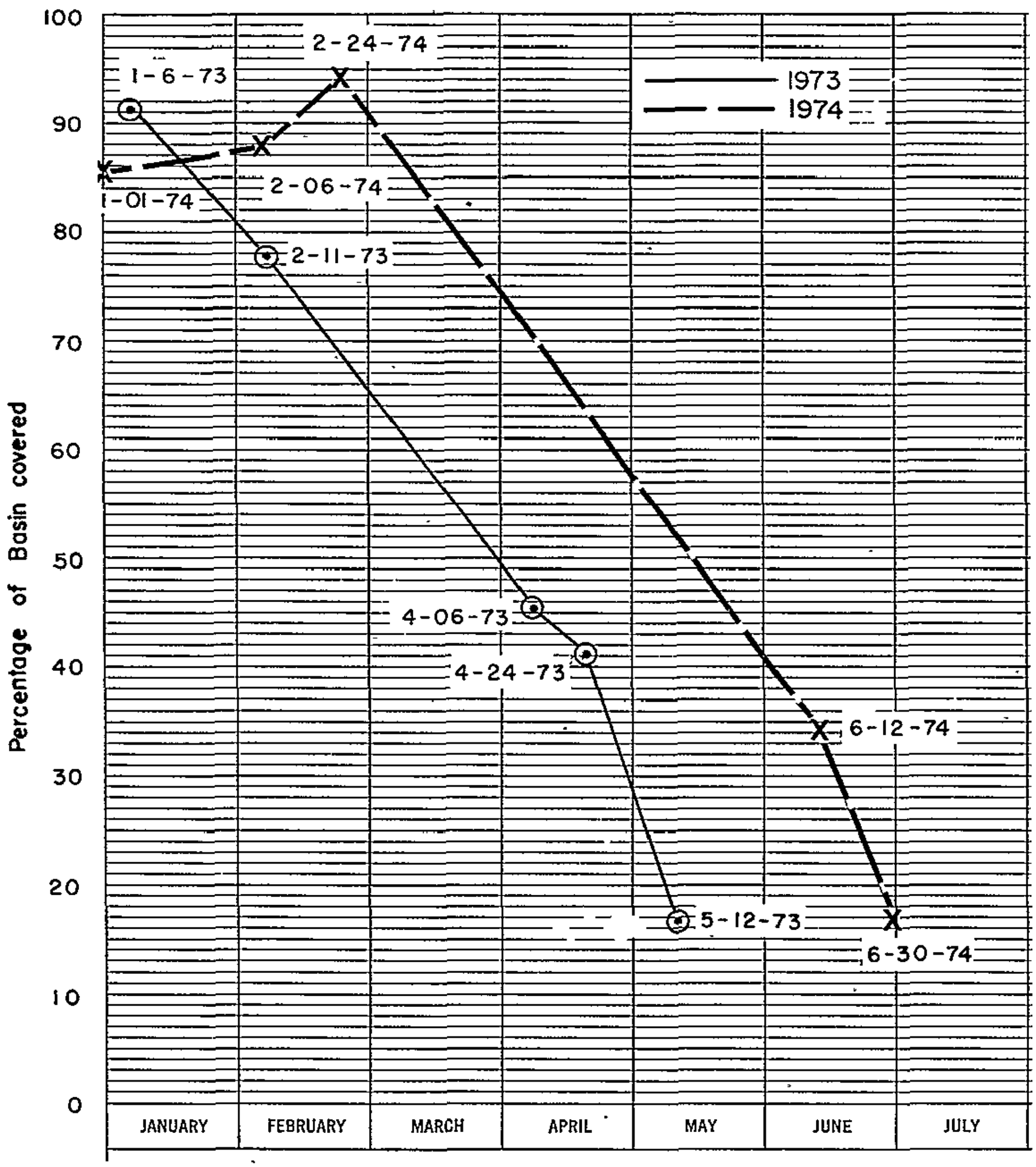
Table 6

UPPER SNAKE BASIN SNOW COVERAGE

Date	Percent of Basin Area Covered by Usable Imagery	Snow Coverage	
		Area (km^2)	Percent of Basin Area*
<u>1973</u>			
29 Mar.	96.9	11,888.0	92.0%
22 May	95.0	5,128.4	40.5
9 Jun.	94.9	1,738.8	13.7
<u>1974</u>			
22 Jun.	96.8	1,942.2	15.3

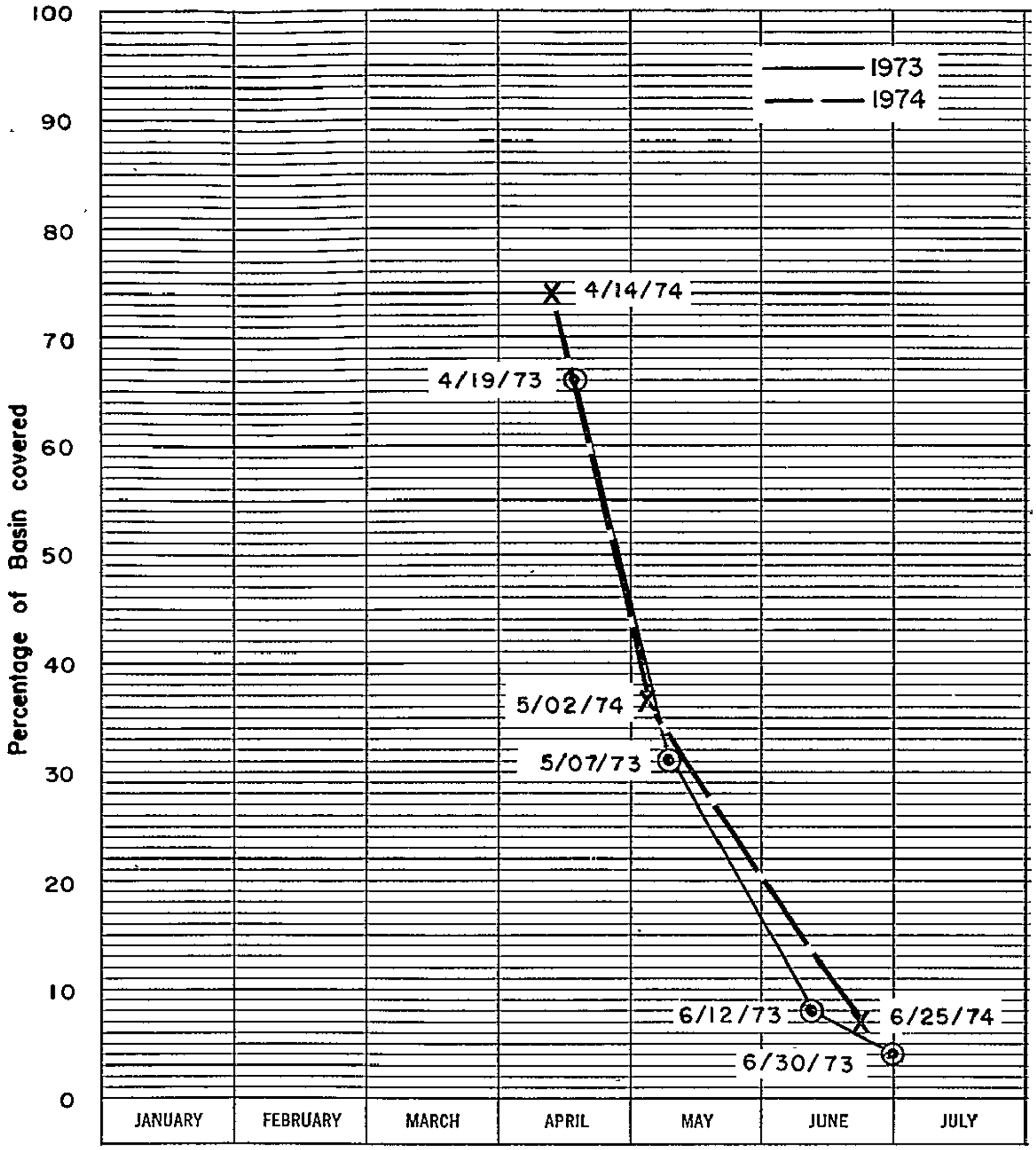
Average elevation ~ 8,000 ft MSL
Basin area = 13,339.6 km^2

*Measured snow area/viewable area.



Snow coverage (percentage of basin) = measured snow area/viewable basin area.
Basin area measured = total basin area = 1,146.0 km^2.

FIGURE 2 NORTH SANTIAM BASIN, ABOVE DETROIT, OREGON, SNOW COVERAGE



Snow coverage (percentage of basin) = measured snow area/viewable basin area
Basin area measured = total basin area = 7,254.0 km^2.

FIGURE 3 BOISE BASIN, ABOVE LUCKY PEAK, IDAHO, SNOW COVERAGE

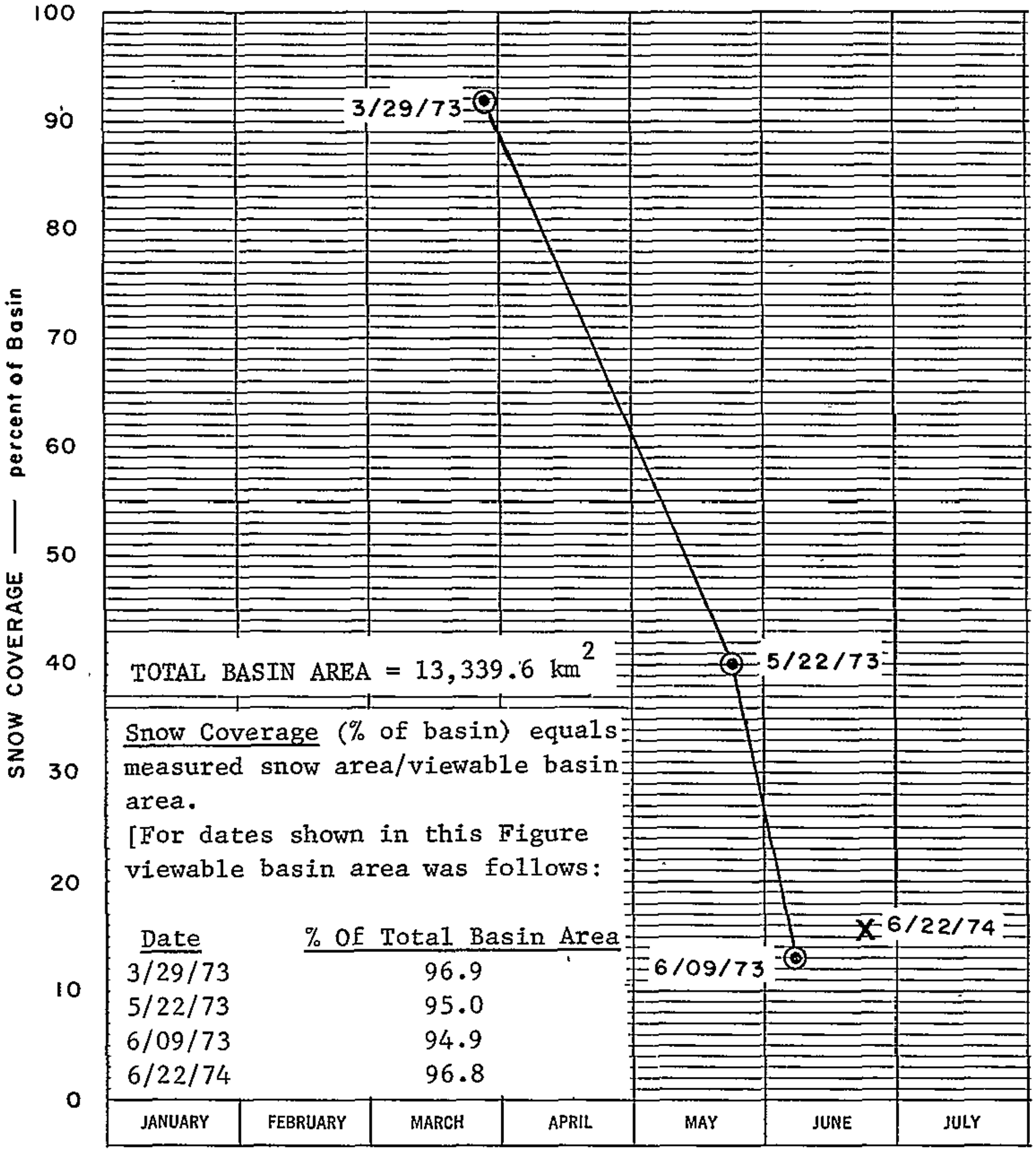


FIGURE 4 UPPER SNAKE BASIN, ABOVE PALISADES, WYOMING, SNOW COVERAGE

III DISTRIBUTION OF SNOW COVER

A North Santiam Basin

The snow cover distributions for the North Santiam Basin by 2.5 x 2.5 km boxes are given in Figures 5 through 14. The values for North Santiam were hand-generated in that the binary count of snow in each box was read from a digital pixel counter by an observer who divided this value by the binary value of a full box area and rounded the quotient to tenths of coverage. In these figures "X" indicates 10/10s coverage.

B. Boise Basin

The snow coverage measurements for the Boise Basin on selected days are given in the printouts captioned Figures 15 through 21. Although to retain the full resolution of the LANDSAT imagery it was necessary to view and measure the snow coverage by sections and then combine the values, only the combined charts of snow coverage over the entire basins are presented in these printouts.

At this point in the research an automated device was developed for the ESIAC which permitted scanning each snow mask in 2.5 x 2.5 km increments and counting the white pixels within each grid box. These values were directly transferred into a PDP-11 computer which turned them into tenths of coverage and printed the results in a Teletype array, simulating the grid box squares.* Four individual Part coverages were then combined manually, resulting in the total basin distribution figures in the printouts. Section IV contains more detail on the recording procedure.

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*Distributions of the snow cover for the four individual Parts of the Boise Basin have been submitted to the sponsor under separate cover.

BASIN: N. SANTIAM

DATE (YEAR, MONTH, DAY): 73-1-6

TOTAL BASIN AREA (SQ. KM): 1146

BASIN AREA MEASURED (SQ. KM): 1146

SNOW AREA (SQ. KM): 858.4

(PERCENT OF BASIN): 74.9

GRID BOX HEIGHT (KM): 2.5

WIDTH (KM): 2.5

UTM ZONE: 9

UTM COORDINATES OF

UPPER LEFT CORNER,

EASTING (KM): 550

NORTHING (KM): 4970

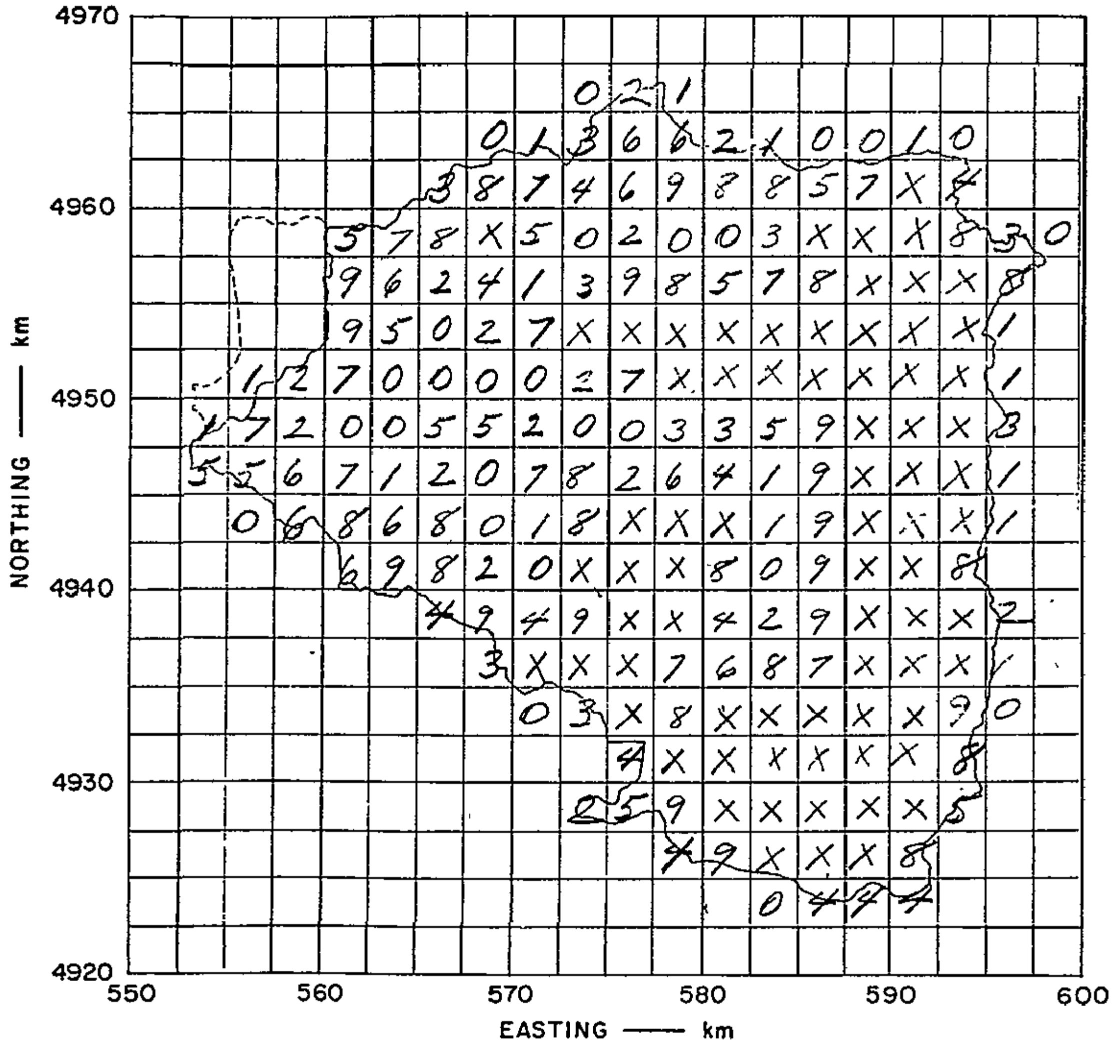


FIGURE 5 JANUARY 6, 1973, NORTH SANTIAM BASIN, SNOW COVER DISTRIBUTION

BASIN: N. SANTIAM

DATE (YEAR, MONTH, DAY): 73-2-11

TOTAL BASIN AREA (SQ. KM): 1146

BASIN AREA MEASURED (SQ. KM): 1146

SNOW AREA (SQ. KM): 891.6

(PERCENT OF BASIN): 77.8

GRID BOX HEIGHT (KM): 2.5

WIDTH (KM): 2.5

UTM ZONE: 9

UTM COORDINATES OF

UPPER LEFT CORNER,

EASTING (KM): 550

NORTHING (KM): 4970

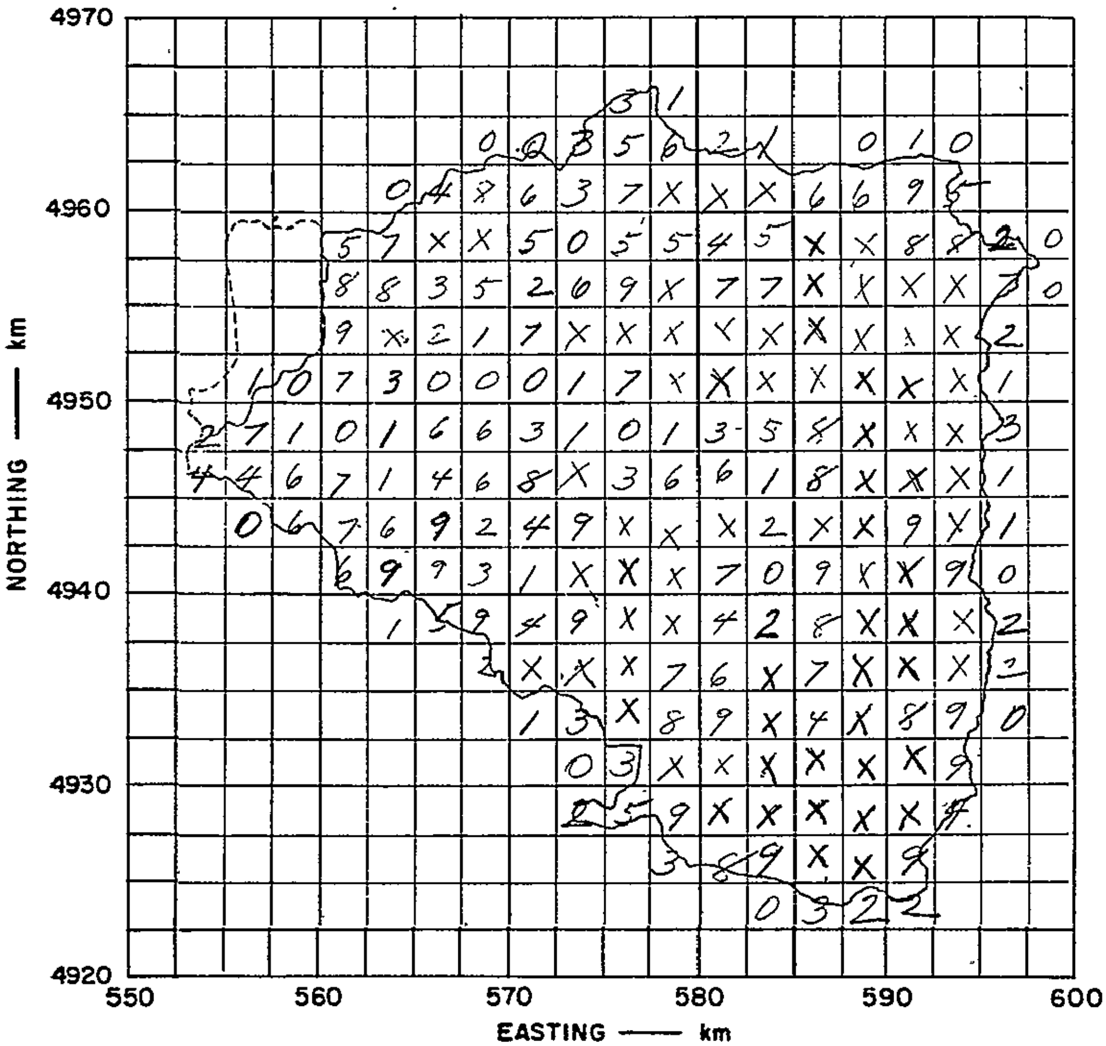


FIGURE 6 FEBRUARY 11, 1973, NORTH SANTIAM BASIN, SNOW COVER DISTRIBUTION

BASIN: N. SANTIAM

DATE (YEAR, MONTH, DAY): 73-4-6

TOTAL BASIN AREA (SQ. KM): 1146

BASIN AREA MEASURED (SQ. KM): 1146

SNOW AREA (SQ. KM): 519.1

(PERCENT OF BASIN): 45.3

GRID BOX HEIGHT (KM): 2.5

WIDTH (KM): 2.5

UTM ZONE: 9

UTM COORDINATES OF UPPER LEFT CORNER,

EASTING (KM): 550

NORTHING (KM): 4970

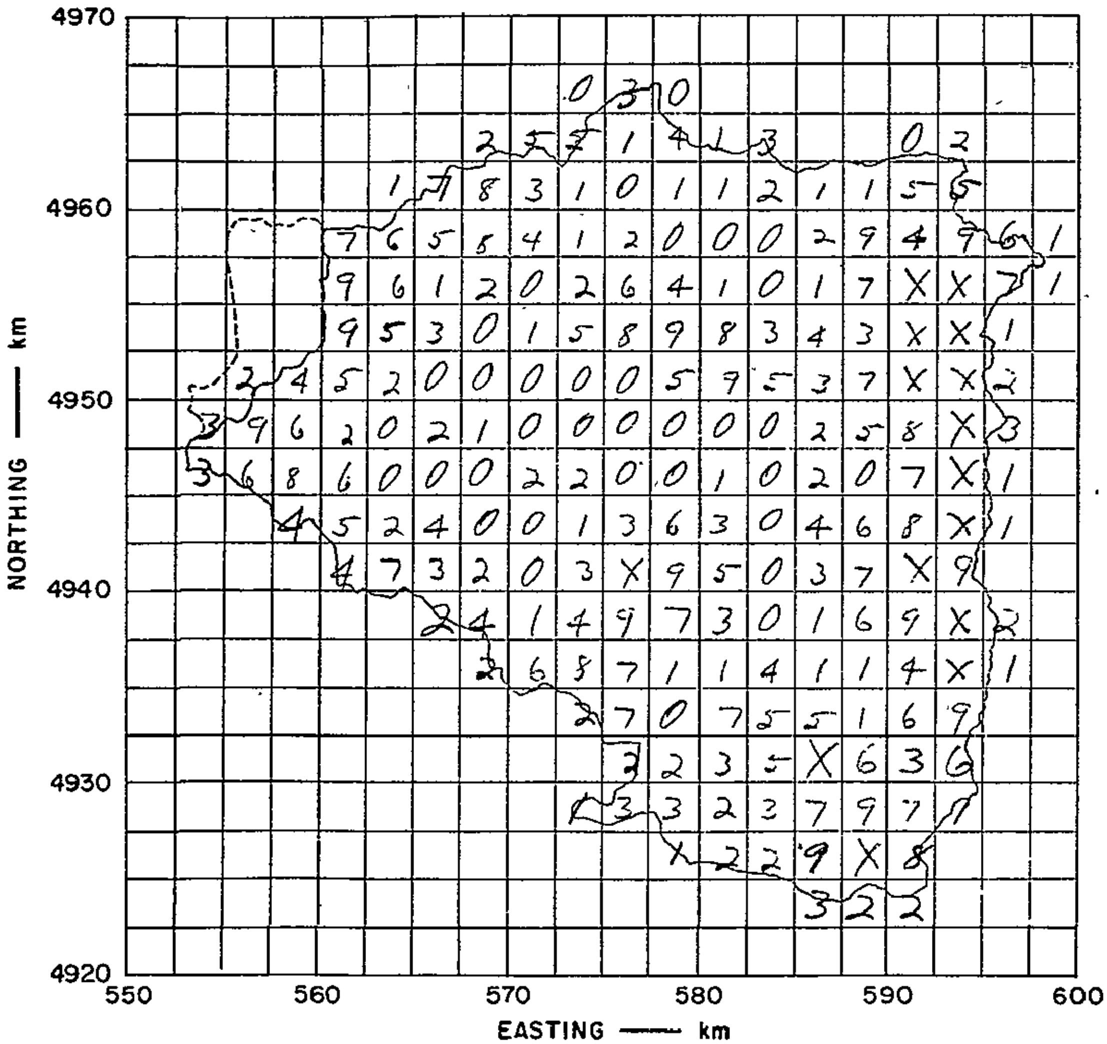


FIGURE 7 APRIL 6, 1973, NORTH SANTIAM BASIN, SNOW COVER DISTRIBUTION

BASIN: N. SANTIAM

DATE (YEAR, MONTH, DAY): 73-4-24

TOTAL BASIN AREA (SQ. KM): 1146

BASIN AREA MEASURED (SQ. KM): 1146

SNOW AREA (SQ. KM): 475.6

(PERCENT OF BASIN): 41.5

GRID BOX HEIGHT (KM): 2.5

WIDTH (KM): 2.5

UTM ZONE: 9

UTM COORDINATES OF UPPER LEFT CORNER,

EASTING (KM): 550

NORTHING (KM): 4970

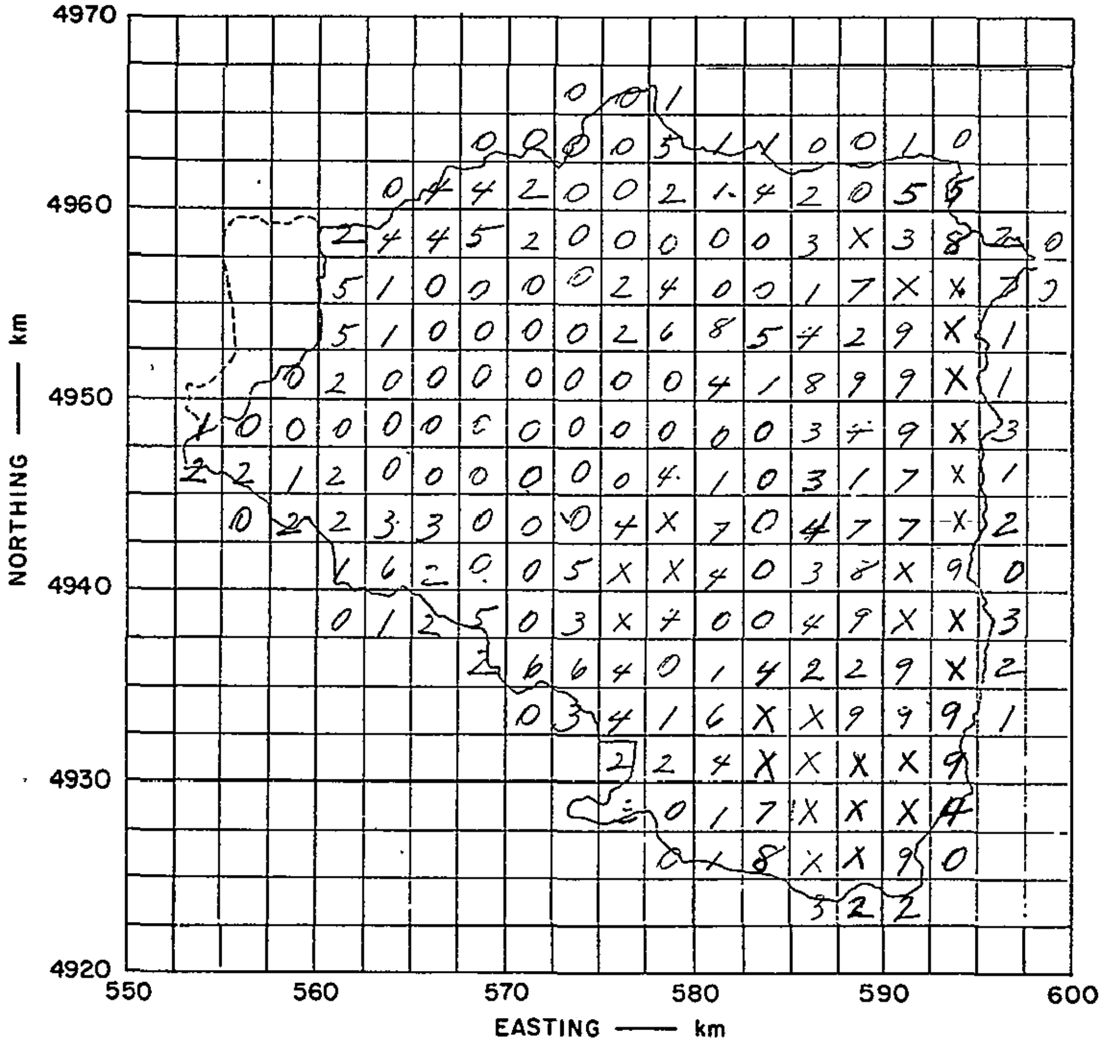


FIGURE 8 APRIL 24, 1973, NORTH SANTIAM BASIN, SNOW COVER DISTRIBUTION

BASIN: N. SANTIAM

DATE (YEAR, MONTH, DAY): 73-5-12

TOTAL BASIN AREA (SQ. KM): 1146

BASIN AREA MEASURED (SQ. KM): 1146

SNOW AREA (SQ. KM): 205.1

(PERCENT OF BASIN): 17.9

GRID BOX HEIGHT (KM): 2.5

WIDTH (KM): 2.5

UTM ZONE: 9

UTM COORDINATES OF
UPPER LEFT CORNER,

EASTING (KM): 550

NORTHING (KM): 4970

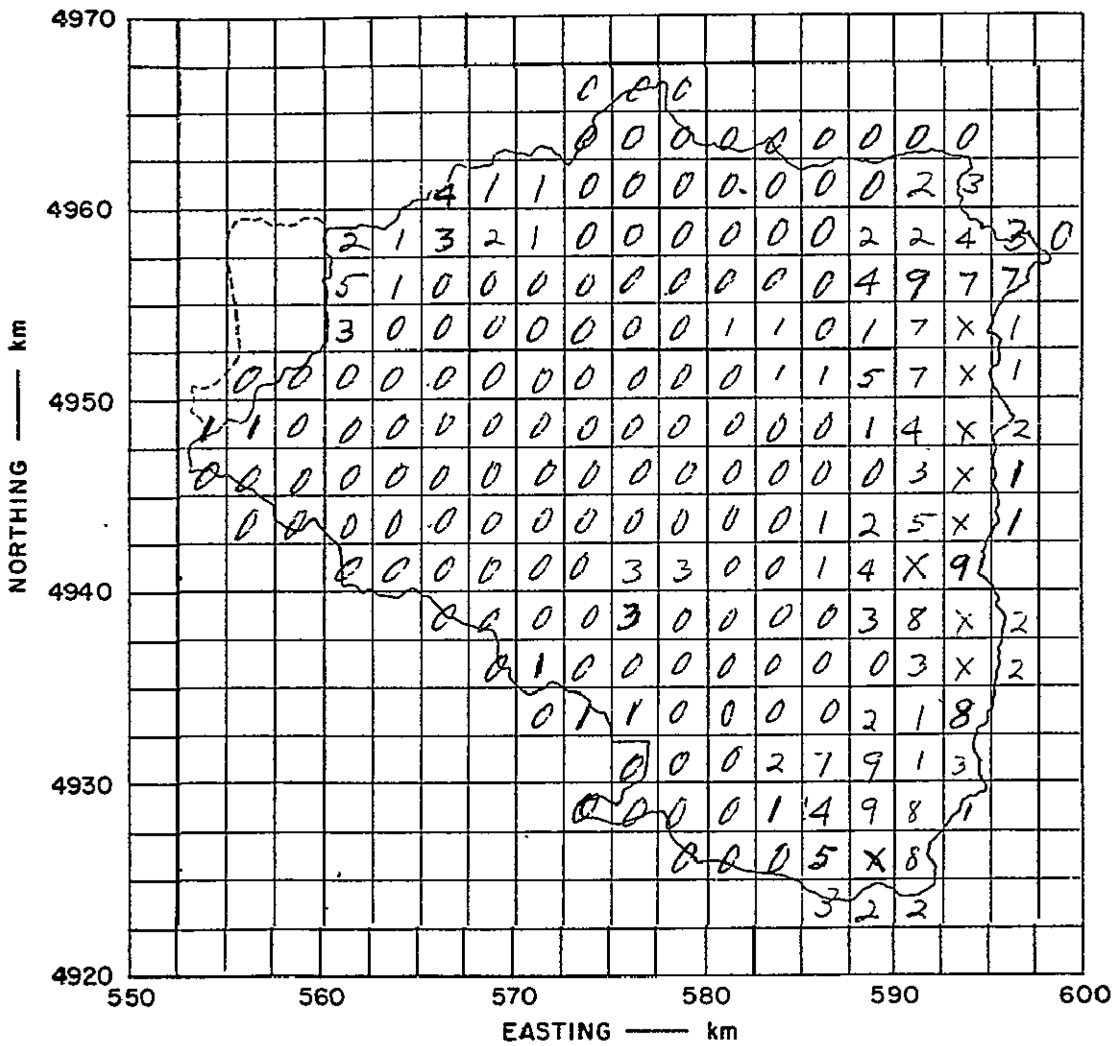


FIGURE 9 MAY 12, 1973, NORTH SAMTIAM BASIN, SNOW COVER DISTRIBUTION

BASIN: N. SANTIAM
DATE (YEAR, MONTH, DAY): 74-1-1
TOTAL BASIN AREA (SQ. KM): 1146
BASIN AREA MEASURED (SQ. KM): 1146
SNOW AREA (SQ. KM): 975.2
(PERCENT OF BASIN): 85.1
GRID BOX HEIGHT (KM): 2.5
WIDTH (KM): 2.5
UTM ZONE: 9
UTM COORDINATES OF
UPPER LEFT CORNER,
EASTING (KM): 550
NORTHING (KM): 4970

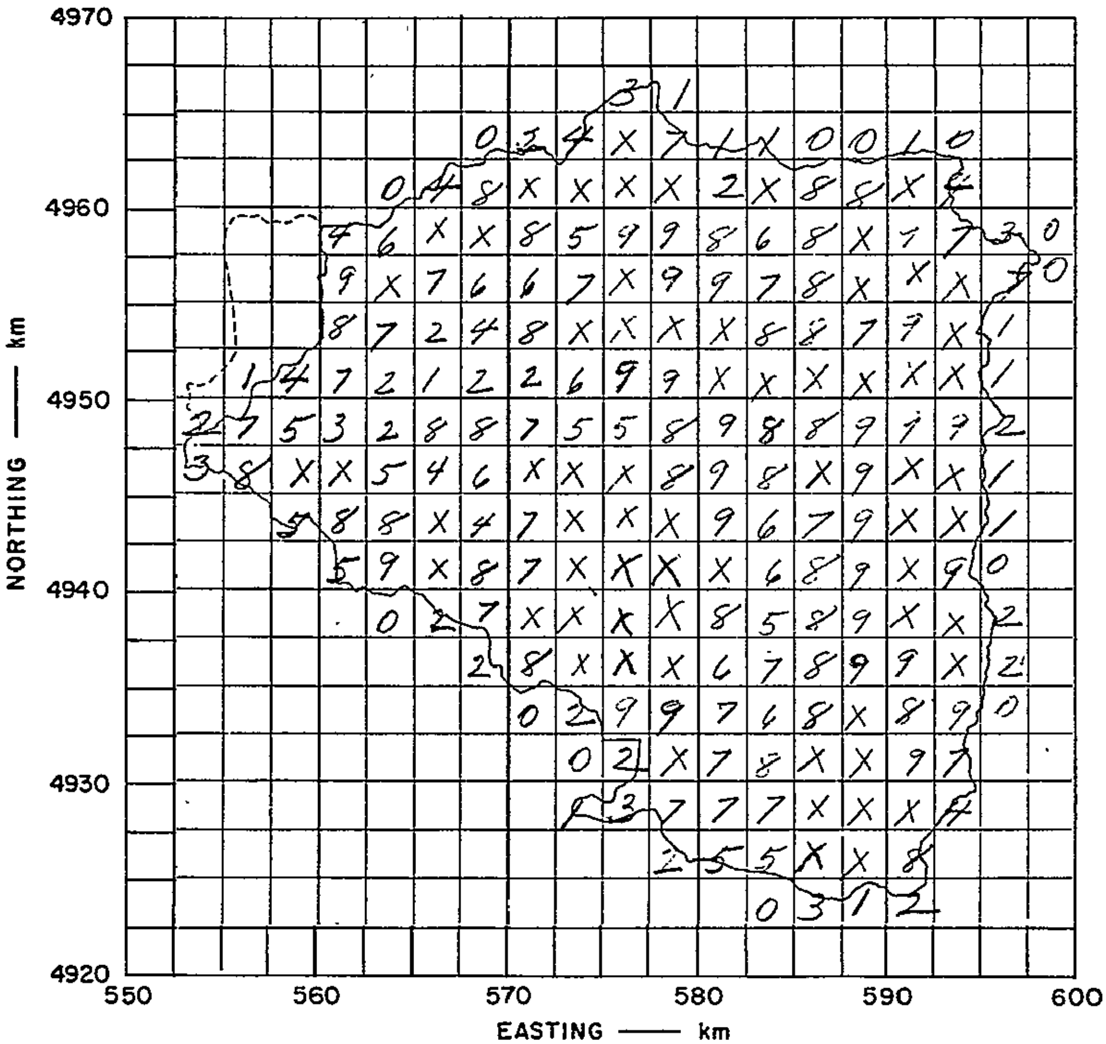


FIGURE 10 JANUARY 1, 1974, NORTH SANTIAM BASIN, SNOW COVER DISTRIBUTION

BASIN: N. SANTIAM

DATE (YEAR, MONTH, DAY): 74-2-6

TOTAL BASIN AREA (SQ. KM): 1146

BASIN AREA MEASURED (SQ. KM): 1146

SNOW AREA (SQ. KM): 1002.8

(PERCENT OF BASIN): 87.5

GRID BOX HEIGHT (KM): 2.5

WIDTH (KM): 2.5

UTM ZONE: 9

UTM COORDINATES OF
UPPER LEFT CORNER,

EASTING (KM): 550

NORTHING (KM): 4970

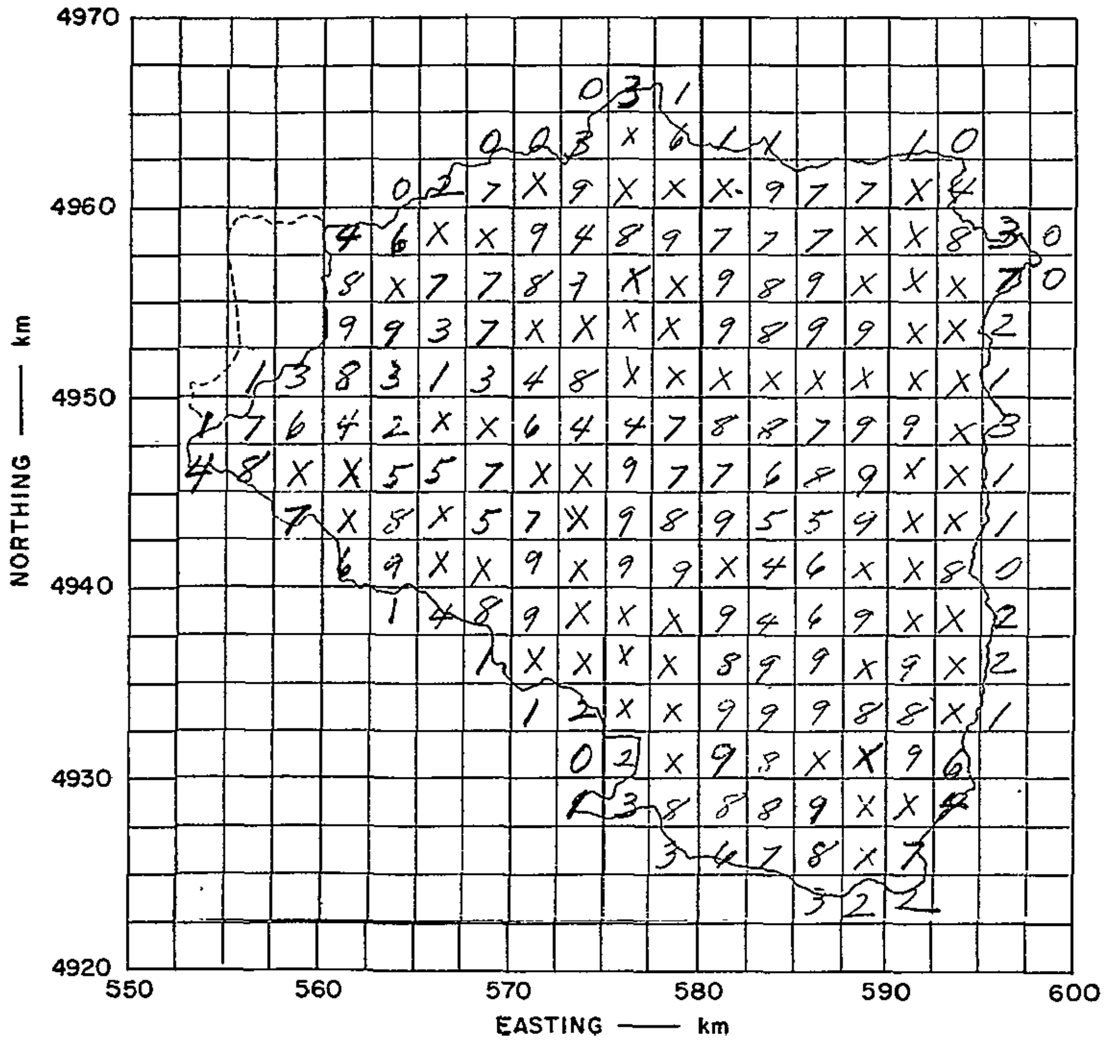


FIGURE 11 FEBRUARY 6, 1974, NORTH SANTIAM BASIN, SNOW COVER DISTRIBUTION

BASIN: N. SANTIAM

DATE (YEAR, MONTH, DAY): 74-2-24

TOTAL BASIN AREA (SQ. KM): 1146

BASIN AREA MEASURED (SQ. KM): 1146

SNOW AREA (SQ. KM): 1080.7

(PERCENT OF BASIN): 94.3

GRID BOX HEIGHT (KM): 2.5

WIDTH (KM): 2.5

UTM ZONE: 9

UTM COORDINATES OF UPPER LEFT CORNER,

EASTING (KM): 550

NORTHING (KM): 4970

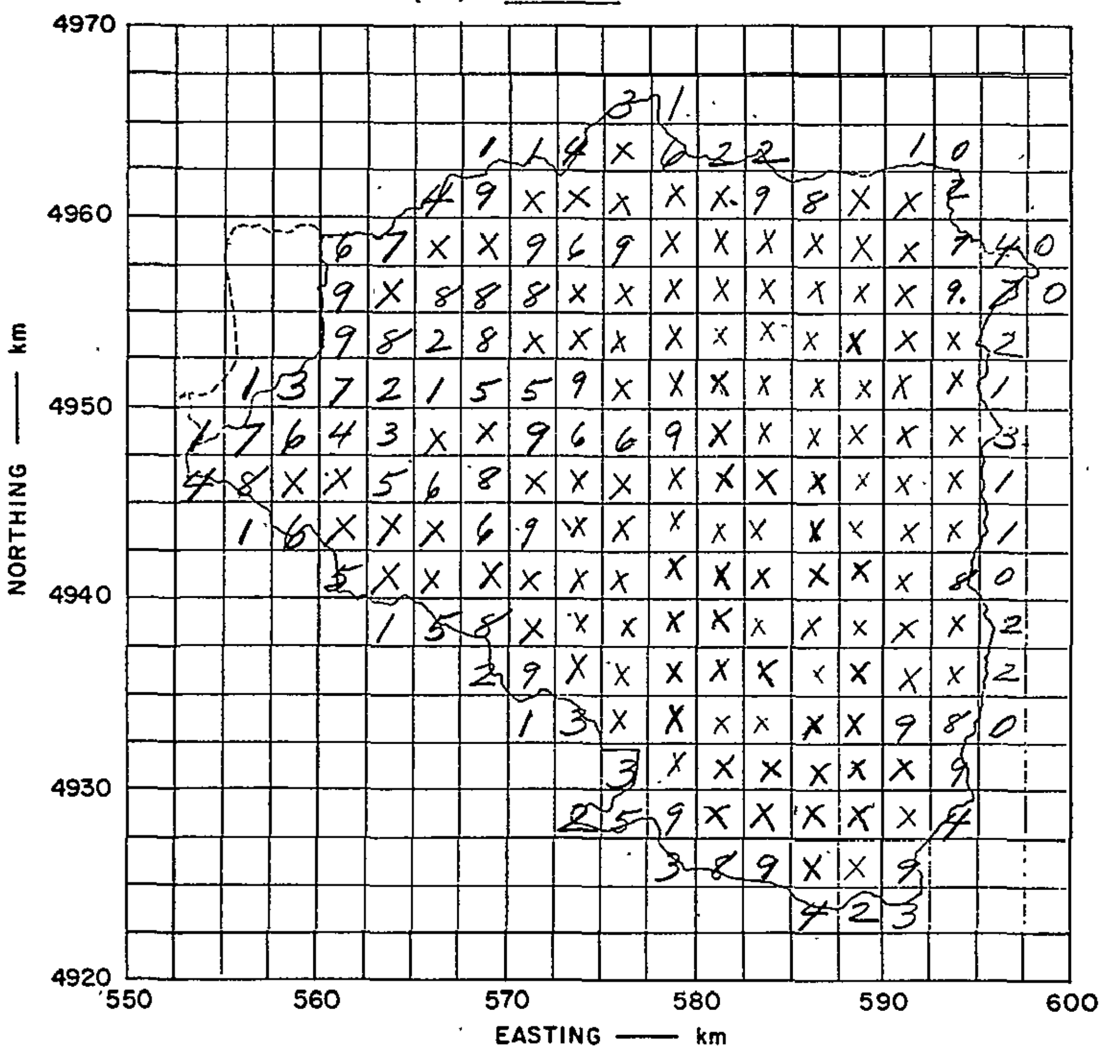


FIGURE 12 FEBRUARY 24, 1974, NORTH SANTIAM BASIN, SNOW COVER DISTRIBUTION

BASIN: N. SANTIAM

DATE (YEAR, MONTH, DAY): 74-6-12

TOTAL BASIN AREA (SQ. KM): 1146

BASIN AREA MEASURED (SQ. KM): 1146

SNOW AREA (SQ. KM): 405.7

(PERCENT OF BASIN): 35.4

GRID BOX HEIGHT (KM): 2.5

WIDTH (KM): 2.5

UTM ZONE: 9

UTM COORDINATES OF UPPER LEFT CORNER,

EASTING (KM): 550

NORTHING (KM): 4970

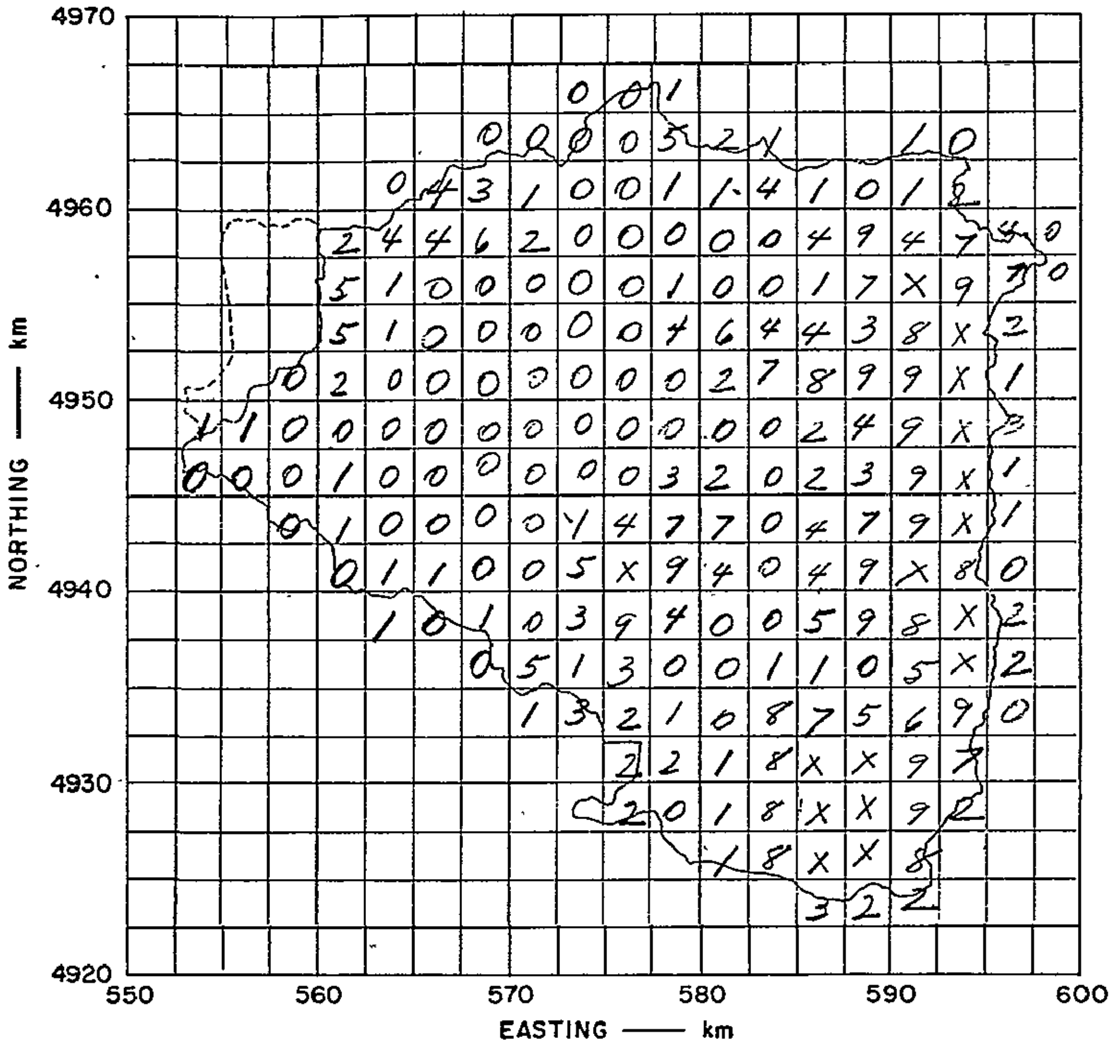


FIGURE 13 JUNE 12, 1974, NORTH SANTIAM BASIN, SNOW COVER DISTRIBUTION

BASIN: N. SANTIAM

DATE (YEAR, MONTH, DAY): 74-6-30

TOTAL BASIN AREA (SQ. KM): 1146

BASIN AREA MEASURED (SQ. KM): 1146

SNOW AREA (SQ. KM): 190.2

(PERCENT OF BASIN): 16.6

GRID BOX HEIGHT (KM): 2.5

WIDTH (KM): 2.5

UTM ZONE: 9

UTM COORDINATES OF UPPER LEFT CORNER,

EASTING (KM): 550

NORTHING (KM): 4970

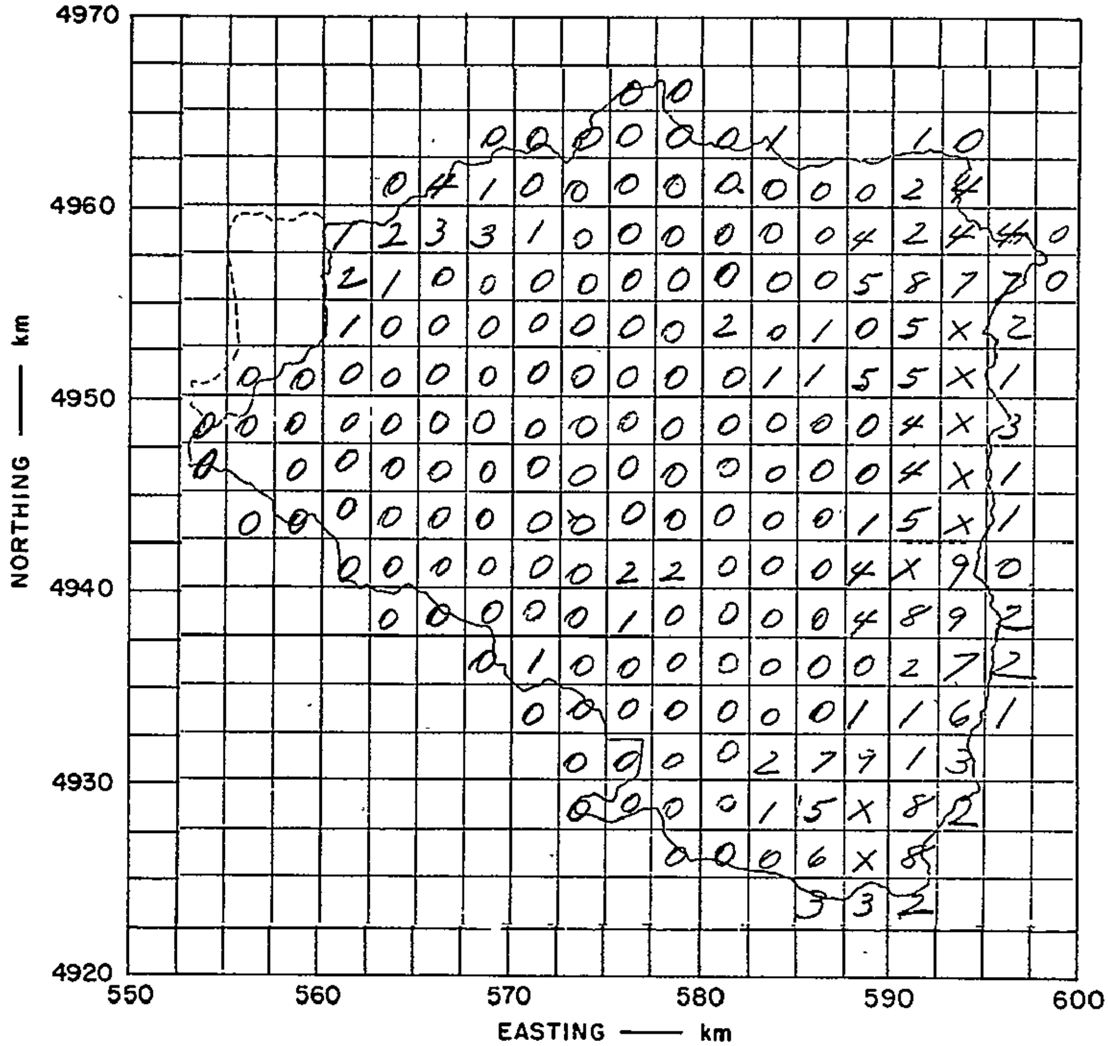


FIGURE 14 JUNE 30, 1974, NORTH SANTIAM BASIN, SNOW COVER DISTRIBUTION

BASIN: BOISE

DATE (YEAR, MONTH, DAY): 73-4-19

TOTAL BASIN AREA (SQ. KM): 7254.0

BASIN AREA MEASURED (SQ. KM): 7254.0

SNOW AREA (SQ. KM): 4750.4

(PERCENT OF BASIN): 65.5

GRID BOX HEIGHT (KM): 2.5

WIDTH (KM): 2.5

UTM ZONE: 11

UTM COORDINATES OF UPPER LEFT CORNER,

EASTING (KM): 570

NORTHING (KM): 4885

UTM ZONE 11

Easting 570km

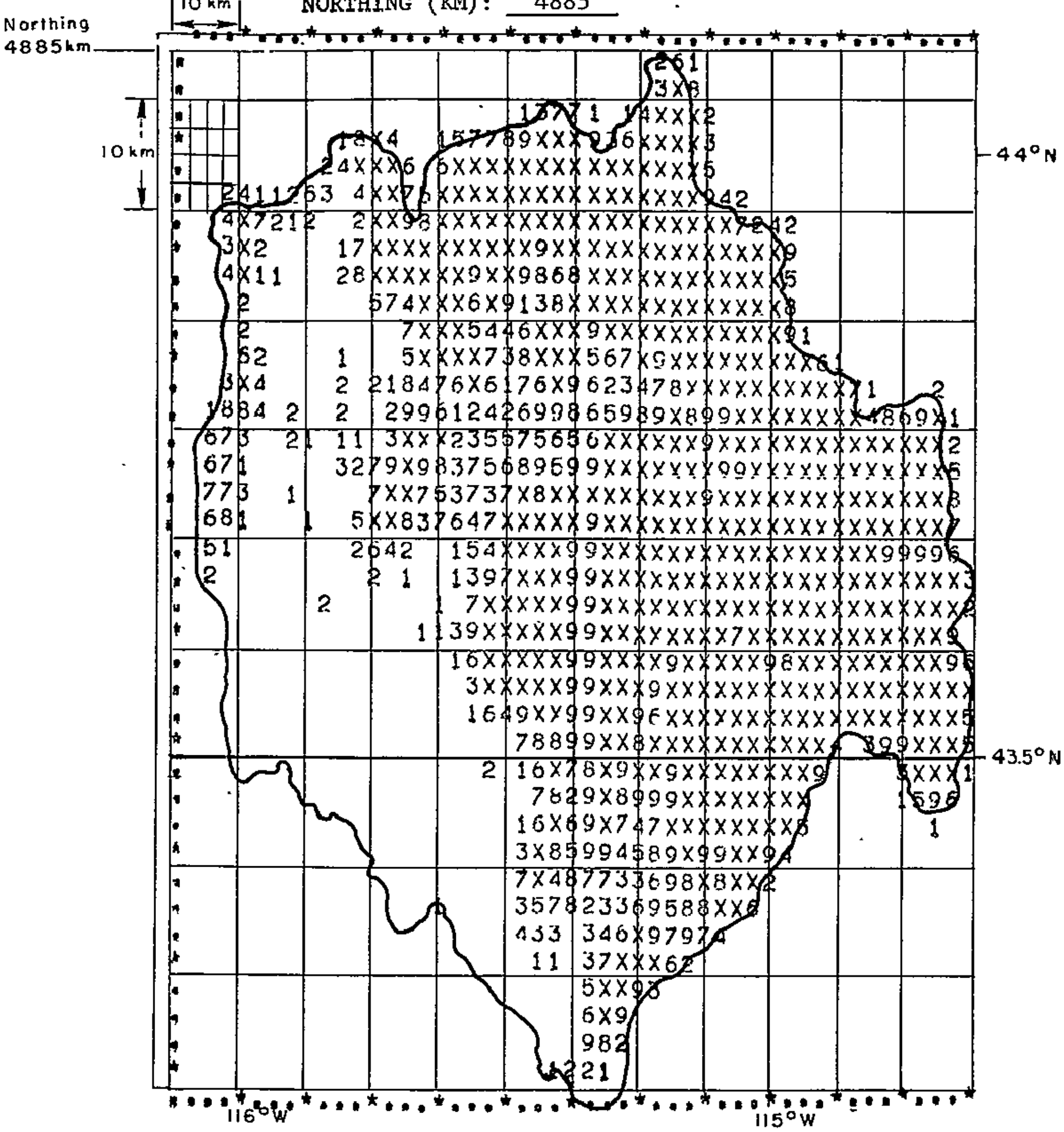


FIGURE 15 APRIL 19, 1973, BOISE BASIN, SNOW COVER DISTRIBUTION

BASIN: BOISE

DATE (YEAR, MONTH, DAY): 73-5-7

TOTAL BASIN AREA (SQ. KM): 7254.0

BASIN AREA MEASURED (SQ. KM): 7254.0

SNOW AREA (SQ. KM): 2270.4

(PERCENT OF BASIN): 31.3

GRID BOX HEIGHT (KM): 2.5

WIDTH (KM): 2.5

UTM ZONE: 11

UTM COORDINATES OF UPPER LEFT CORNER,

EASTING (KM): 570

NORTHING (KM): 4885

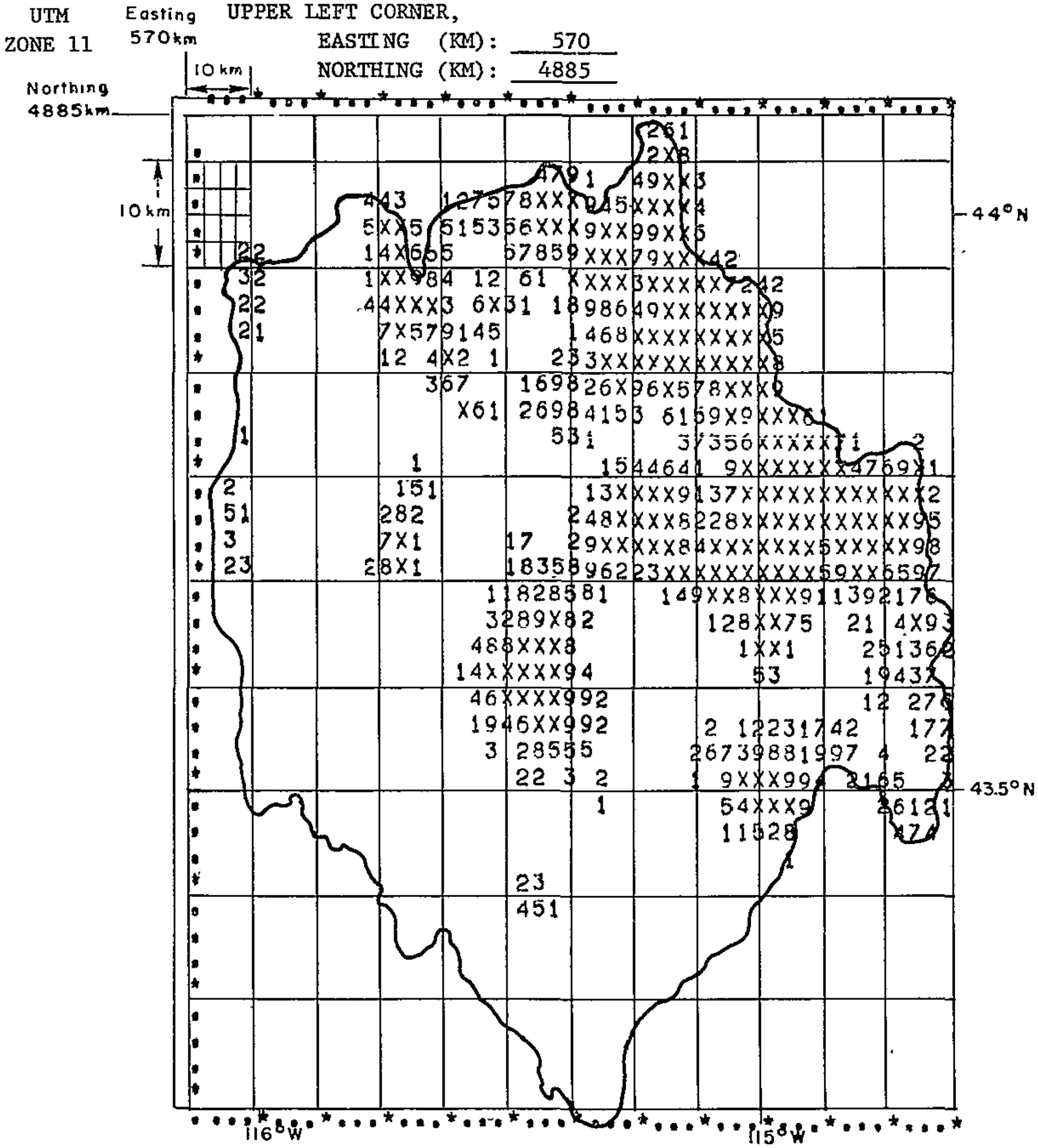


FIGURE 16 MAY 7, 1973, BOISE BASIN, SNOW COVER DISTRIBUTION

BASIN: BOISE

DATE (YEAR, MONTH, DAY): 73-6-12

TOTAL BASIN AREA (SQ. KM): 7254.0

BASIN AREA MEASURED (SQ. KM): 7254.0

SNOW AREA (SQ. KM): 594.1

(PERCENT OF BASIN): 8.2

GRID BOX HEIGHT (KM): 2.5

WIDTH (KM): 2.5

UTM ZONE: 11

UTM COORDINATES OF
UPPER LEFT CORNER,

EASTING (KM): 570

NORTHING (KM): 4885

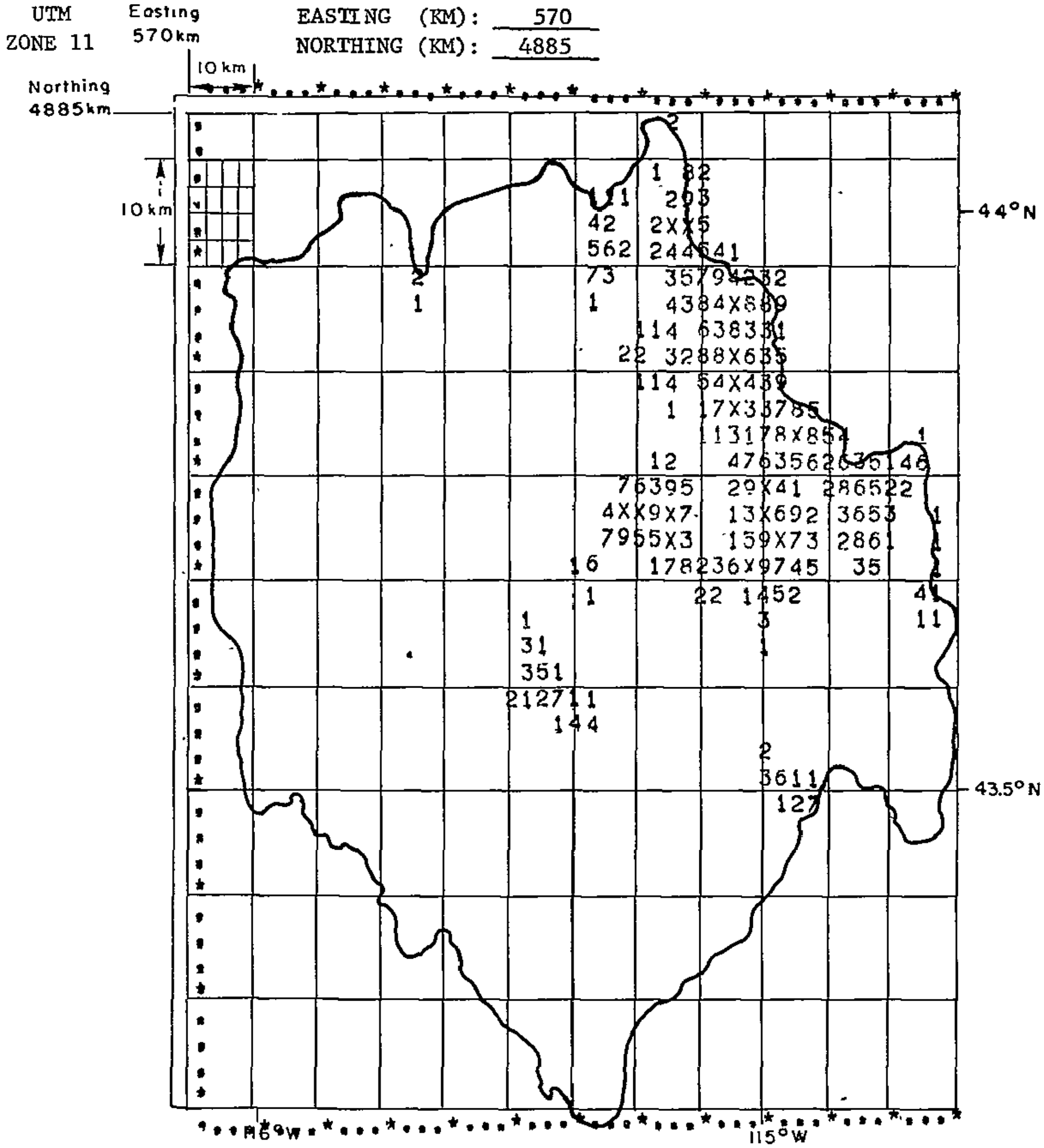


FIGURE 17 JUNE 12, 1973, BOISE BASIN, SNOW COVER DISTRIBUTION

BASIN: BOISE

DATE (YEAR, MONTH, DAY): 73-6-30

TOTAL BASIN AREA (SQ. KM): 7254.0

BASIN AREA MEASURED (SQ. KM): 7254.0

SNOW AREA (SQ. KM): 284.6

(PERCENT OF BASIN): 3.9

GRID BOX HEIGHT (KM): 2.5

WIDTH (KM): 2.5

UTM ZONE: 11

UTM COORDINATES OF UPPER LEFT CORNER,

EASTING (KM): 570

NORTHING (KM): 4885

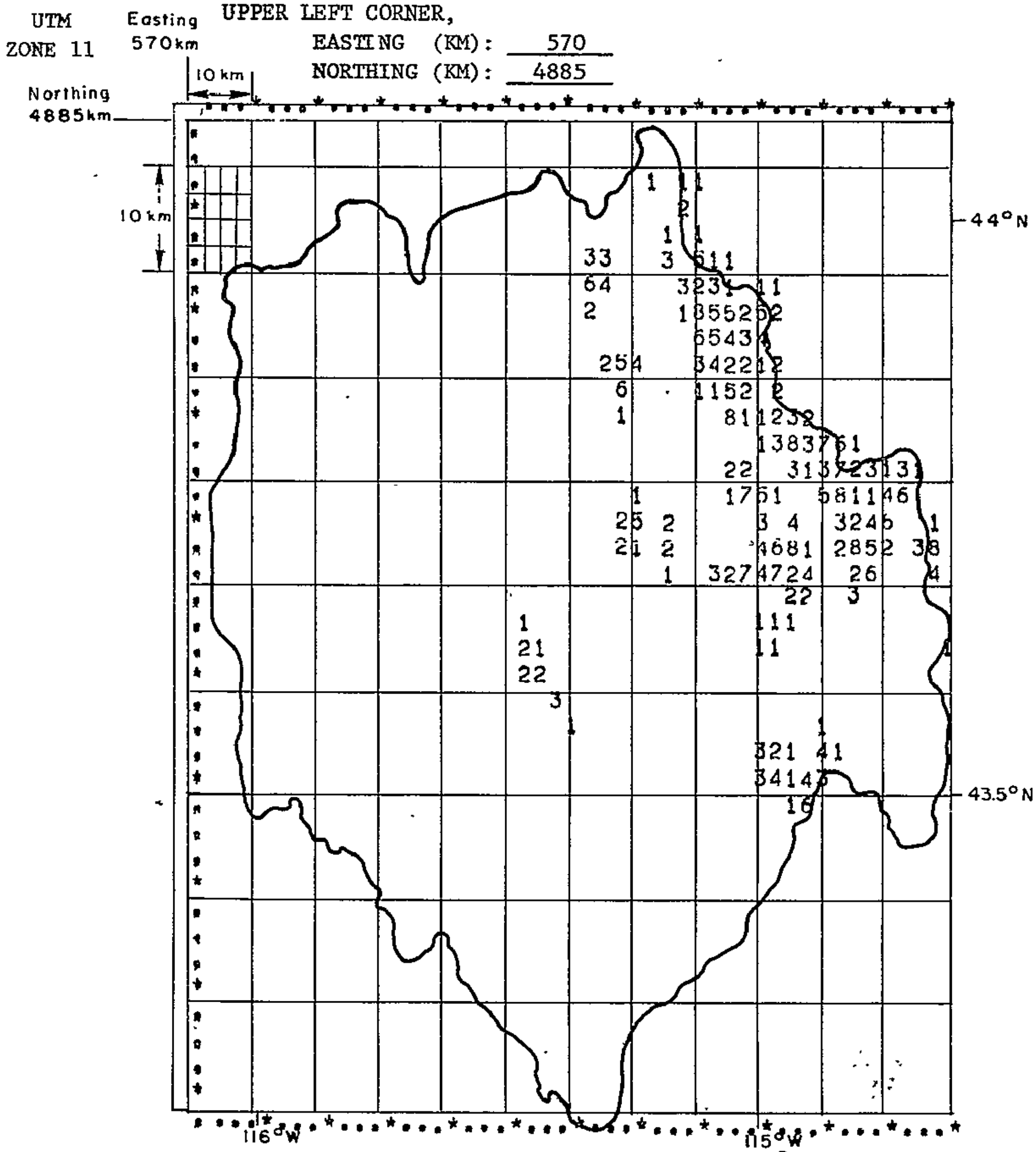


FIGURE 18 JUNE 30, 1973, BOISE BASIN, SNOW COVER DISTRIBUTION

BASIN: BOISE

DATE (YEAR, MONTH, DAY): 74-4-14

TOTAL BASIN AREA (SQ. KM): 7254.0

BASIN AREA MEASURED (SQ. KM): 7254.0

SNOW AREA (SQ. KM): 5377.0

(PERCENT OF BASIN): 74.1

GRID BOX HEIGHT (KM): 2.5

WIDTH (KM): 2.5

UTM ZONE: 11

UTM COORDINATES OF UPPER LEFT CORNER,

EASTING (KM): 570

NORTHING (KM): 4885

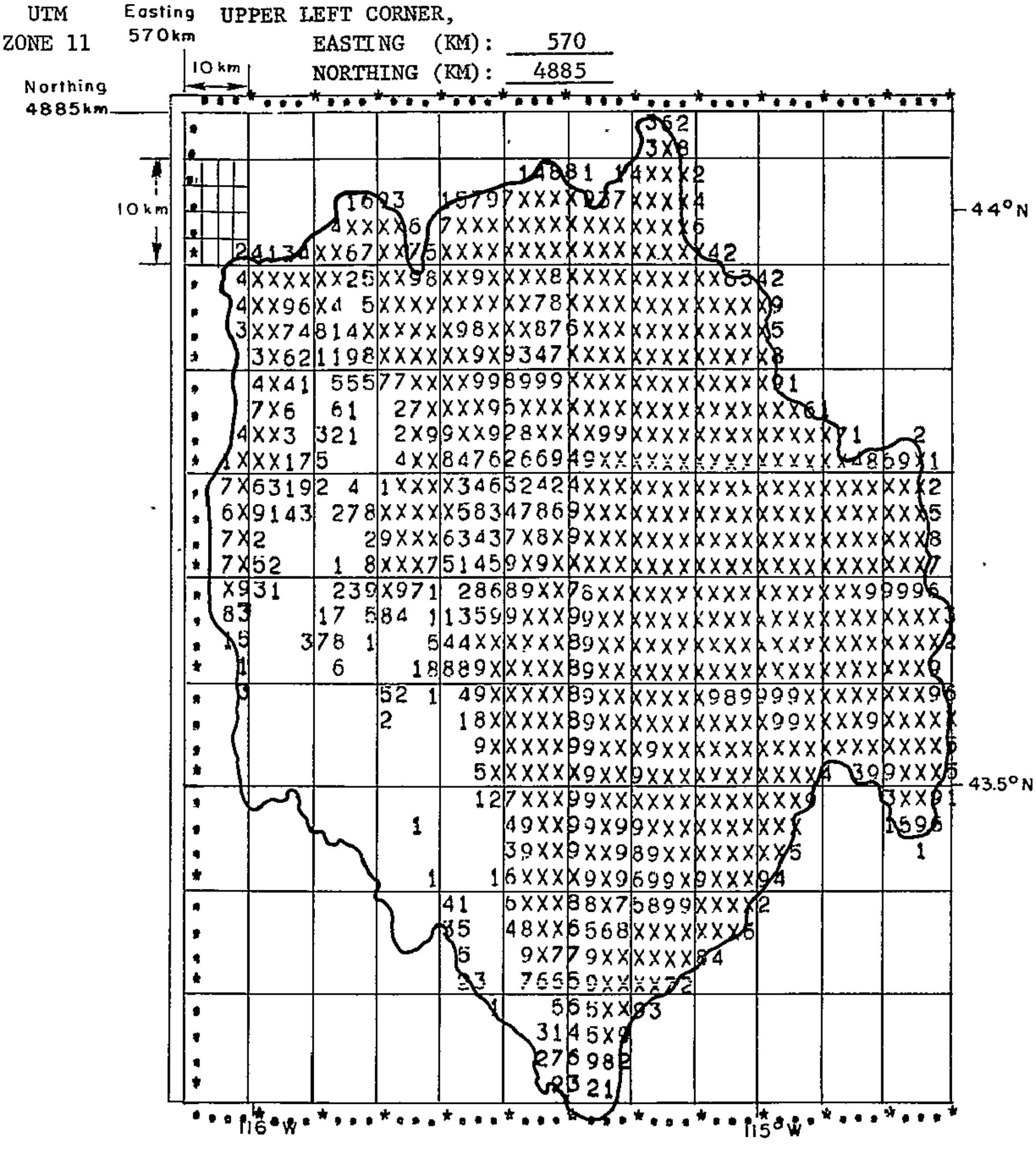


FIGURE 19 APRIL 18, 1974, BOISE BASIN, SNOW COVER DISTRIBUTION

BASIN: BOISE

DATE (YEAR, MONTH, DAY): 74-5-2

TOTAL BASIN AREA (SQ. KM): 7254.0

BASIN AREA MEASURED (SQ. KM): 7254.0

SNOW AREA (SQ. KM): 2609.5

(PERCENT OF BASIN): 36.0

GRID BOX HEIGHT (KM): 2.5

WIDTH (KM): 2.5

UTM ZONE: 11

UTM COORDINATES OF

UPPER LEFT CORNER,

EASTING (KM): 570

NORTHING (KM): 4885

UTM ZONE 11 Easting 570km

Northing 4885km

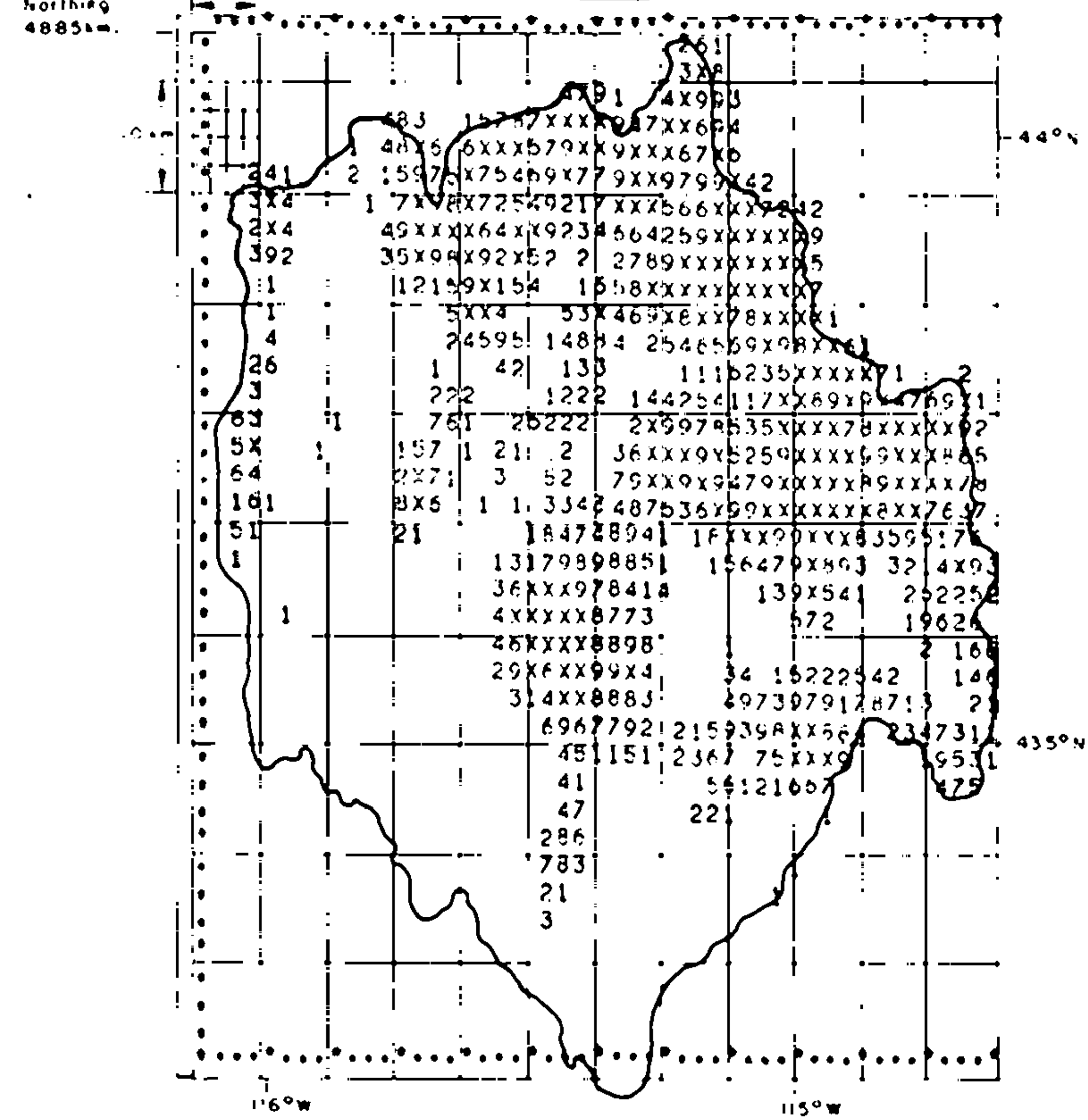


FIGURE 20 MAY 21, 1974, BOISE BASIN, SNOW COVER DISTRIBUTION

BASIN: BOISE

DATE (YEAR, MONTH, DAY): 74-6-25

TOTAL BASIN AREA (SQ. KM): 7254.0

BASIN AREA MEASURED (SQ. KM): 7254.0

SNOW AREA (SQ. KM): 504.5

(PERCENT OF BASIN): 7.0

GRID BOX HEIGHT (KM): 2.5

WIDTH (KM): 2.5

UTM ZONE: 11

UTM COORDINATES OF

UPPER LEFT CORNER,

EASTING (KM): 570

NORTHING (KM): 4885

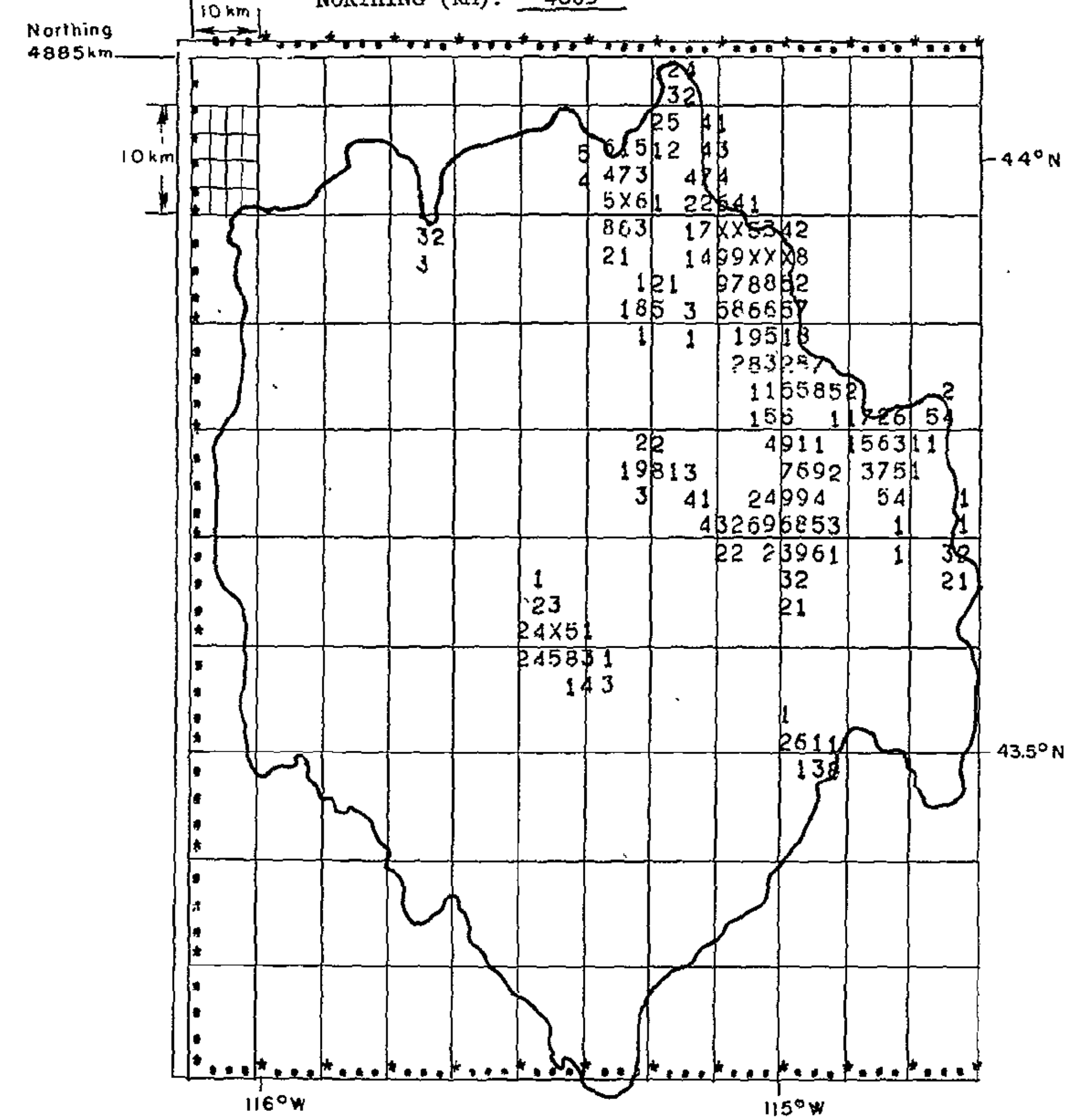


FIGURE 21 JUNE 25, 1974, BOISE BASIN, SNOW COVER DISTRIBUTION

C Upper Snake Basin

The snow coverage measurements for the Upper Snake Basin are given in the computer printouts, Figure 22 through 25. To retain the full resolution it was necessary to subdivide the basin into 11 sectors or Parts, view each sector separately, and obtain snow measurements in each sector.* The automatic device for reading the binary product in the 2.5 x 2.5 km grid array, described previously, was used to obtain the measurements. At this stage of the research the computer program was extended to combine the snow distributions of the Parts. These total basin distributions are those given in the printouts.

*Distributions of the snow cover for the 11 individual Parts of the Upper Snake Basin have been submitted to the sponsor under separate cover.

BASIN= UPPER SNAKE ABOVE PALISADES
DATE (YEAR,MONTH,DAY)= 73, 3,29
TOTAL BASIN AREA (SQ. KM.)= 13339.6
BASIN AREA MEASURED (SQ. KM.)= 12929.0
SNOW AREA (SQ. KM)= 11880.0
(PERCENT OF BASIN)= 91.9
GRID BOX HEIGHT (KM)= 2.5
GRID BOX WIDTH (KM)= 2.5
UTM ZONE= 12
UPPER LEFT CORNER,
EASTING (KM)= 440
NORTHING (KM)= 4930

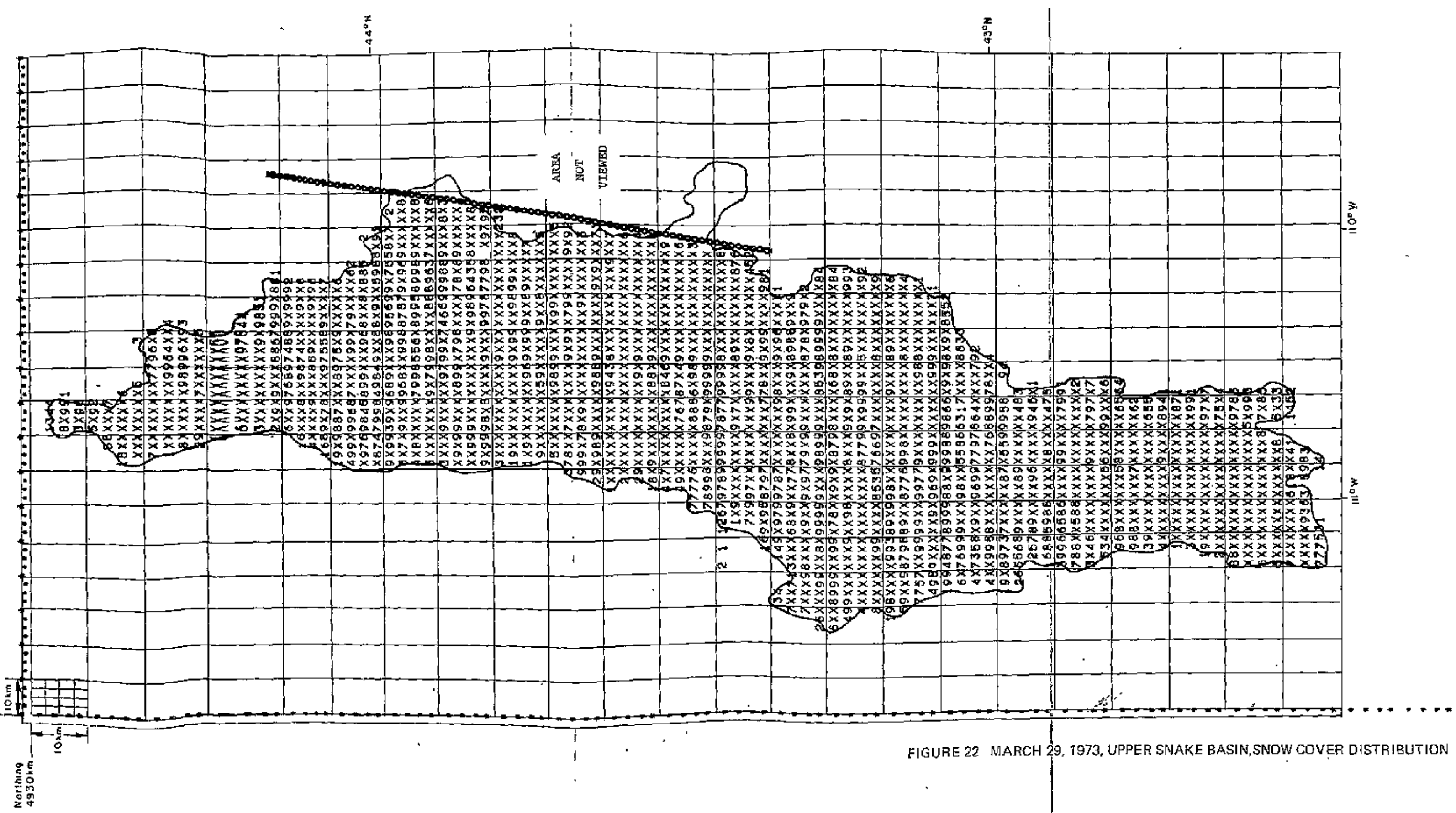


FIGURE 22 MARCH 29, 1973, UPPER SNAKE BASIN,SNOW COVER DISTRIBUTION

BASIN= UPPER SNAKE ABOVE PALISADES
DATE (YEAR,MONTH,DAY)= 73, 5,22
TOTAL BASIN AREA (SQ. KM.)= 13339.6
BASIN AREA MEASURED (SQ. KM.)= 12677.8
SNOW AREA (SQ. KM)= 5128.4
(PERCENT OF BASIN)= 40.5

GRID BOX HEIGHT (KM)= 2.5
GRID BOX WIDTH (KM)= 2.5
UTM ZONE= 12
UPPER LEFT CORNER,
EASTING (KM)= 440
NORTHING (KM)= 4930

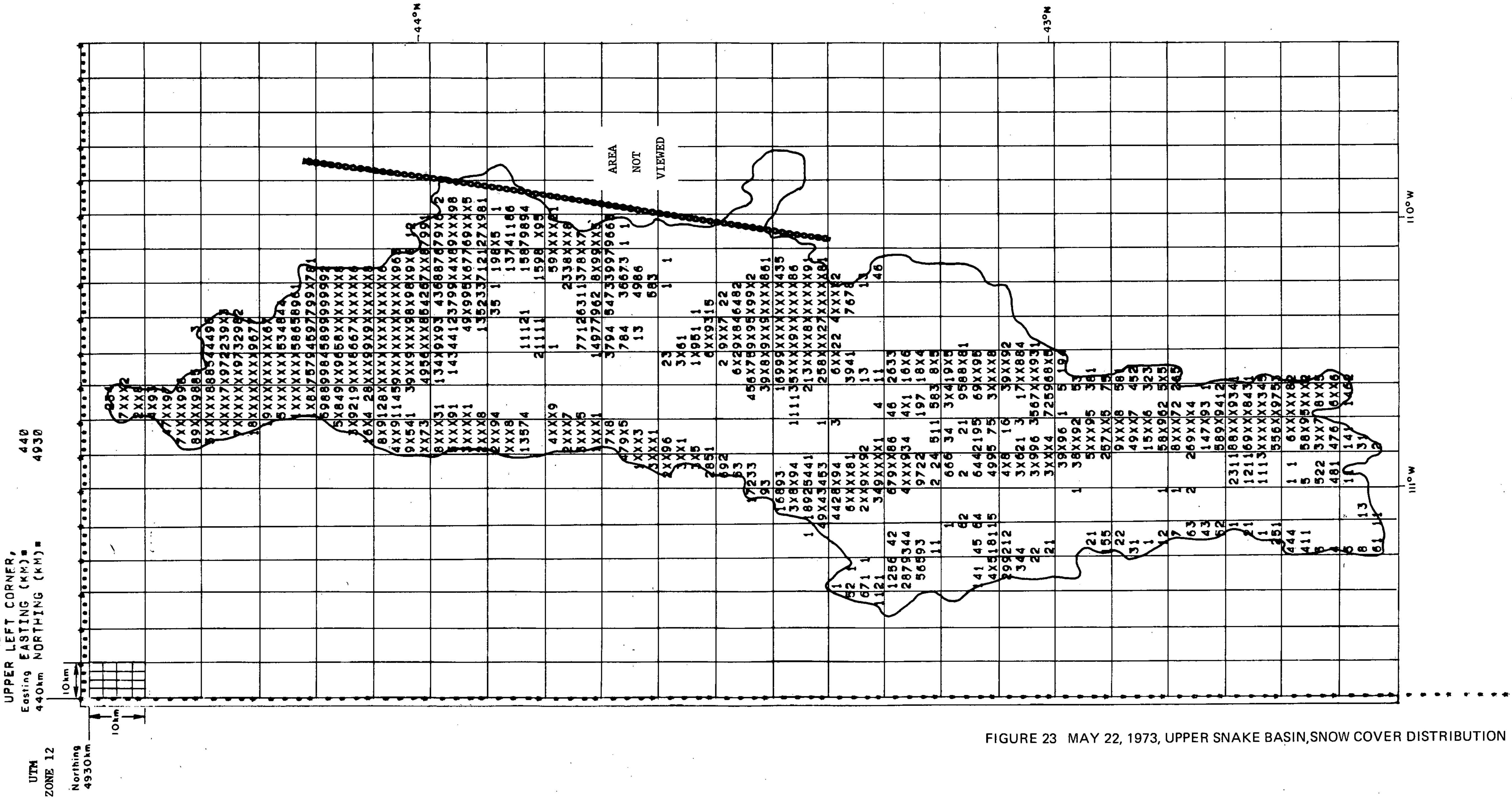


FIGURE 23 MAY 22, 1973, UPPER SNAKE BASIN,SNOW COVER DISTRIBUTION

FOLDOUT FRAME 1

FOLDOUT FRAME 2

BASIN= UPPER SNAKE ABOVE PALISADES
DATE (YEAR,MONTH,DAY)= 73, 6, 9
TOTAL BASIN AREA (SQ. KM.)= 13339.6
BASIN AREA MEASURED (SQ. KM.)= 12655.8
SNOW AREA (SQ. KM)= 1738.8
(PERCENT OF BASIN)= 13.7

GRID BOX HEIGHT (KM)= 2.5
GRID BOX WIDTH (KM)= 2.5
UTM ZONE= 12
UPPER LEFT CORNER,
EASTING (KM)= 440
NORTHING (KM)= 4930

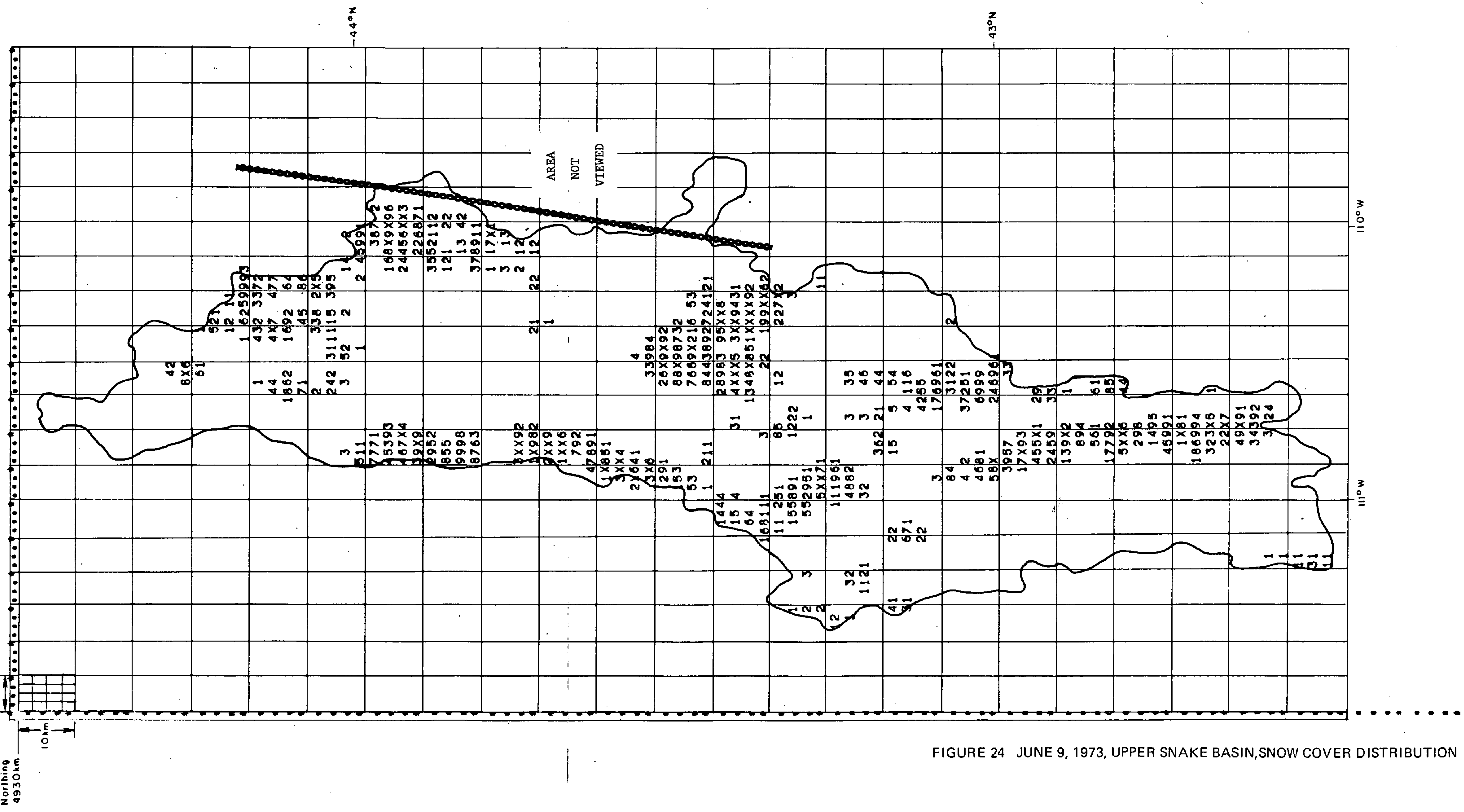


FIGURE 24 JUNE 9, 1973, UPPER SNAKE BASIN, SNOW COVER DISTRIBUTION

BASIN= UPPER SNAKE ABOVE PALISADES
DATE (YEAR,MONTH,DAY)= 74, 6,22
TOTAL BASIN AREA (SQ. KM.)= 13339.6
BASIN AREA MEASURED (SQ. KM.)= 12915.4
SNOW AREA (SQ. KM)= 1974.2
(PERCENT OF BASIN)= 15.3
GRID BOX HEIGHT (KM)= 2.5
GRID BOX WIDTH (KM)= 2.5
UTM ZONE= 12
UPPER LEFT CORNER,
EASTING (KM)= 440
NORTHING (KM)= 4930

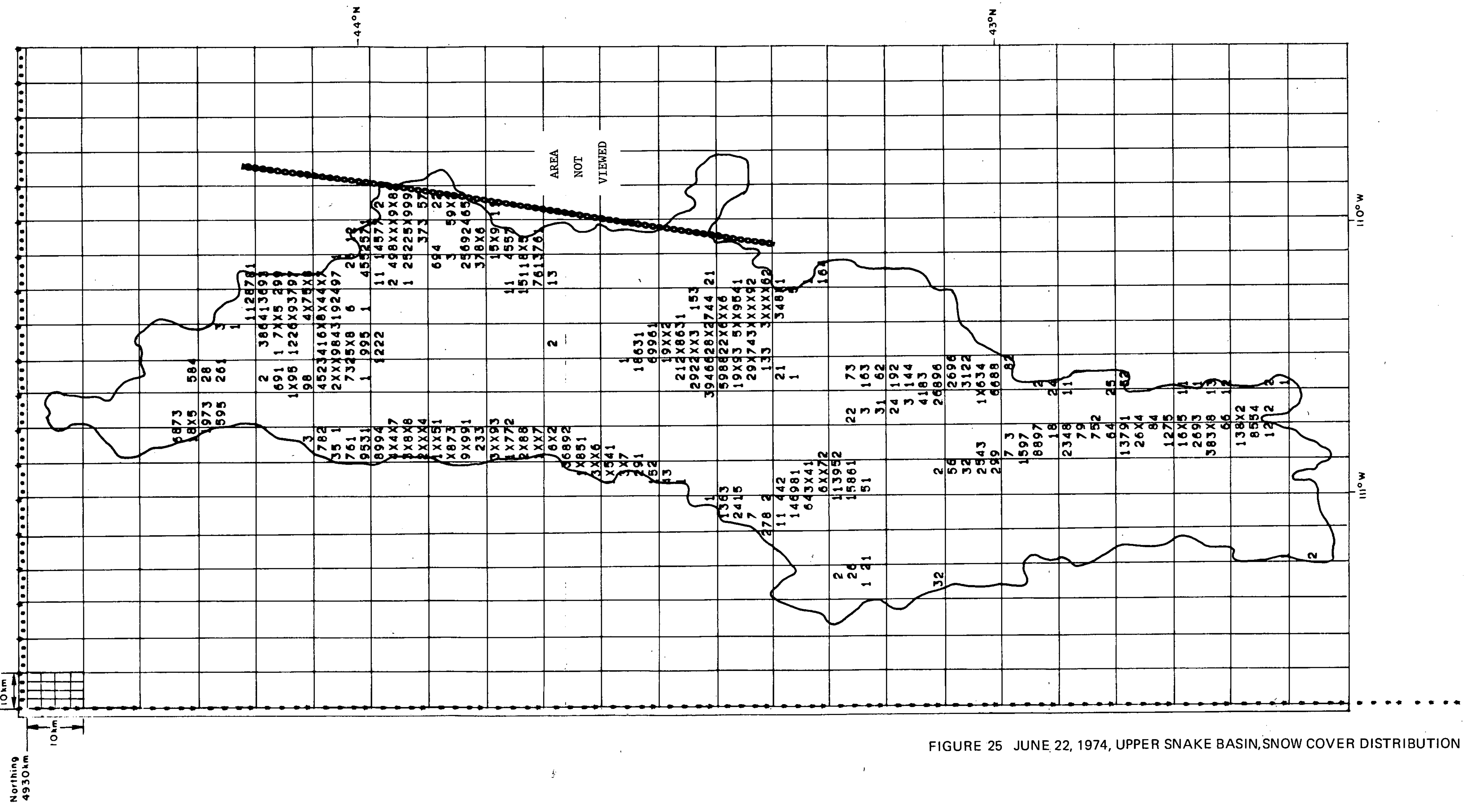


FIGURE 25 JUNE 22, 1974, UPPER SNAKE BASIN, SNOW COVER DISTRIBUTION

FOLDOUT FRAME 1

FOLDOUT FRAME 2

IV MEASUREMENT TECHNIQUES

There were three phases of measurement in this research effort: off-line scene preparation; creation of binary snow maps through edited, single-band radiance thresholding; and measurement of the resultant binary product, either directly from the ESIAC or by an interface of ESIAC with a PDP-11 computer.

A Off-Line Scene Preparation

This activity included the study of basin characteristics, and the construction of contour elevation masks, basin outline masks, Universal Transverse Mercator (UTM) grids, and drainage pattern maps as overlays for the LANDSAT imagery.

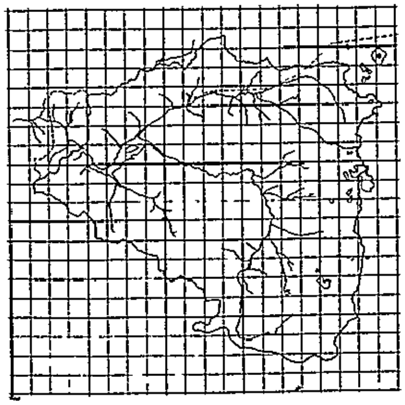
1 Basin Characteristics

These basins, by virtue of disparate size and terrain, present certain characteristics bearing directly on the problem of snow measurement:

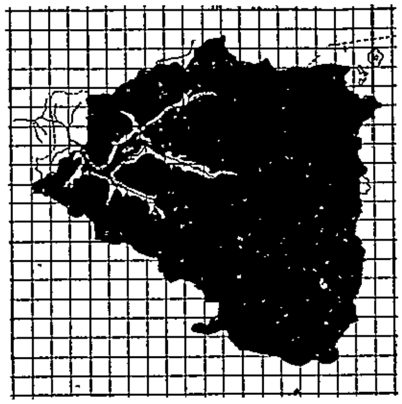
a North Santiam Basin

The North Santiam Basin, about 1,146 km^2 in area, is located on the western slope of the Cascade Range. The basin has a mean elevation of approximately 3,865 ft MSL; virtually all of the basin lies above 2,000 ft, but only about 5% is above the 6,000 ft elevation, as shown in Figure 26.

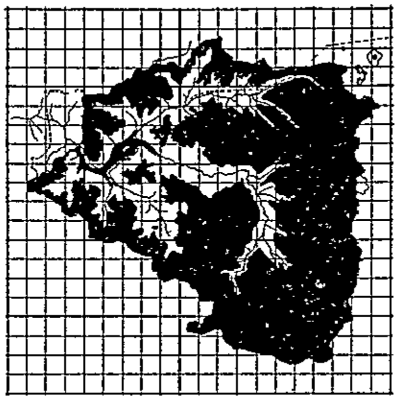
By virtue of its location and exposure, the North Santiam Basin receives the full effect of winter storms that penetrate the area; the Coast Range to the west is not of sufficient elevation to modify



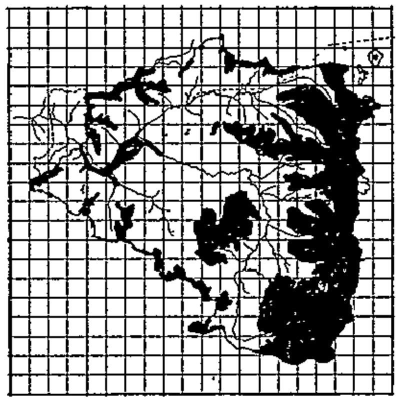
Surface



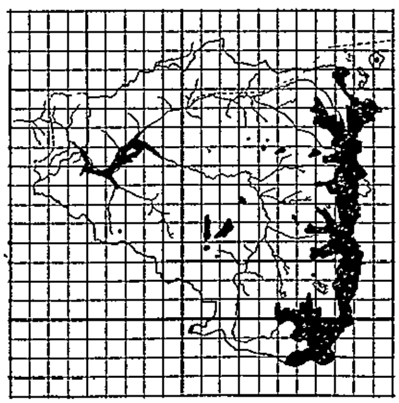
2000 ft or higher



3000 ft or higher

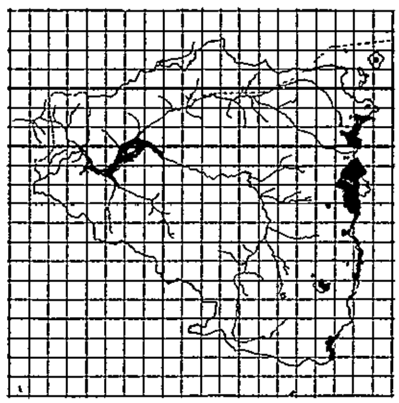


4000 ft or higher



5000 ft or higher

Selected Contour Elevation



6000 ft or higher

FIGURE 26 NORTH SANTIAM BASIN, SELECTED CONTOUR ELEVATIONS

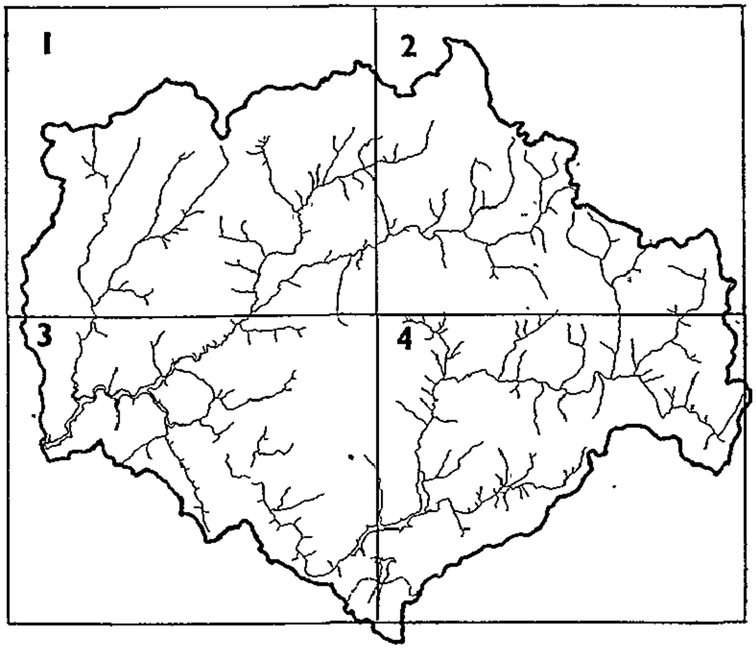
the weather systems greatly. Snow measurements in this basin are directly affected by the fact that, because of the relatively low mean elevation, snow may melt rapidly after occurrence, particularly at the beginning of the snow season. Since the basic mean slope is rather gentle, large areas of snow melt can occur with only a 1,000-ft elevation difference. Also because of its low mean elevation, much of the snow extends into the forest cover; the basin area above tree line is relatively small. The region is heavily forested except for the highest elevations of the Cascade Range from Mt. Jefferson northwards. It is commercially logged, with the result that the basin is studded with "clear-cuts" or areas devoid of dense growth. Because snow can be seen in these clear-cuts, they provide an important check on the extent of snow cover.

b Boise Basin

The area of the basin is approximately 7,254 km^2, with a base elevation of about 4,000 ft and a mean elevation of about 6,200 ft MSL, as shown in Figure 27. The basin includes the Boise Mountains in the western portion, with elevations extending to about 6,000 ft; the Soldier mountains in the central and southern portions, with elevations to 8,000 ft; and the Sawtooth Range in the northeast portion, with elevations to above 8,000 ft. The entire basin is of sufficient elevation that significant areas of snow are acquired and retained through the winter and spring. The principal permanent snow pack is located on the western slopes and ridges of the Sawtooth Range, in the eastern portion of the basin. The western and central portions of the basin are forested, but vegetation becomes much less dense in the Sawtooth Range above 6,000 ft.

c Upper Snake Basin

This basin includes the drainage systems in Jackson Lake and the Palisades Reservoir, as shown in Figure 28. The area of the

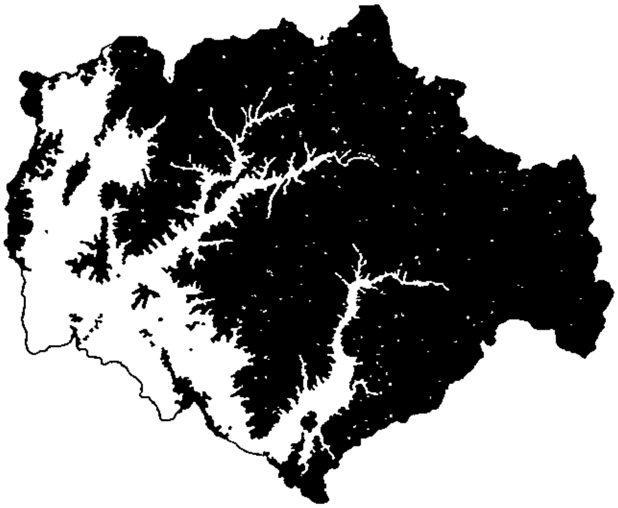


Surface

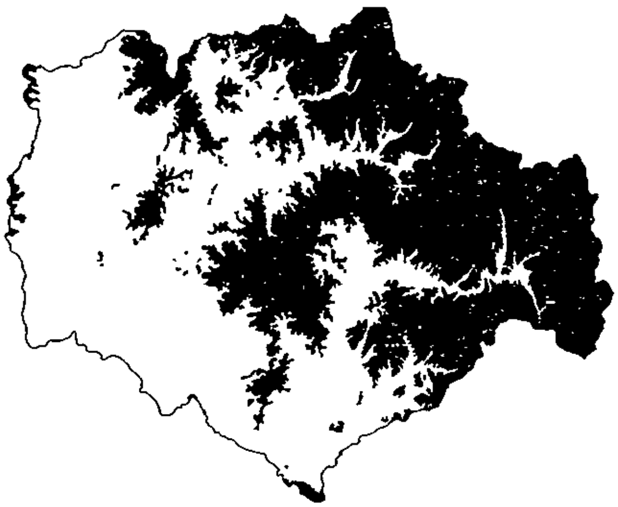
4000 ft or higher

Selected Contour Elevation

FIGURE 27 BOISE BASIN, SELECTED CONTOUR ELEVATIONS

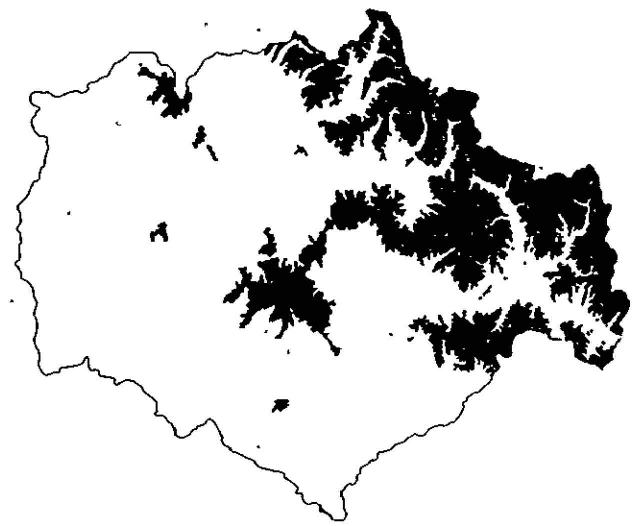


5000 ft or higher



6000 ft or higher

FIGURE 27 BOISE BASIN, SELECTED CONTOUR ELEVATIONS (Continued)



7000 ft or higher

8000 ft or higher

FIGURE 27 BOISE BASIN, SELECTED CONTOUR ELEVATIONS (Concluded)

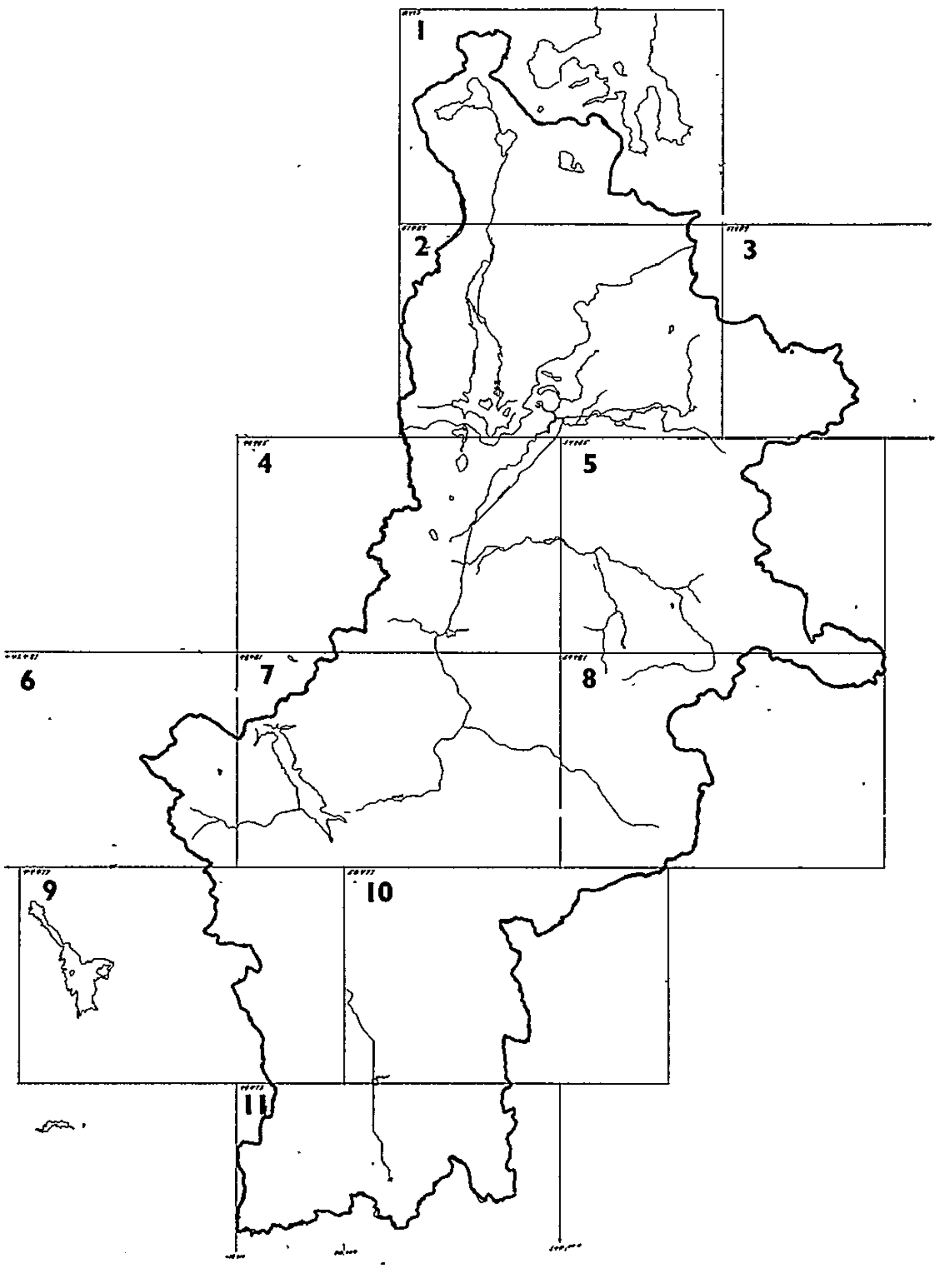


FIGURE 28 UPPER SNAKE BASIN, DRAINAGE MAP

basin is approximately 13,340 km^2; virtually all of it lies above 6,000 ft, with a mean elevation near 7,900 ft MSL, as shown in Figure 29. The basin mountain systems extend to over 10,000 ft in height. These include the Pitchstone Plateau in the far north; the Teton Range in the western upper half; the Gros Ventre Range in the eastern central portion; the Salt River Range and the Wyoming Range, which run north-south and parallel to each other, in the southern portions of the basin; and the Webster Range located on the far western edge of the southern portion. There are two broad valleys--Jackson Hole in the northern portion and Starr Valley in the south. The entire basin is of sufficient elevation that snow is present year-round on a substantial amount of the basin area above 9,000 or 10,000 ft. Forest cover ranges from medium to sparse.

2 Contour Elevation Masks

These masks were generated by tracing selected contours, using even 1,000s of ft, onto white drafting paper; then painting black that portion of the basin lying at elevations higher than the contour value (as shown in Figures 26, 27, and 29); and photographing the resulting mask as a negative transparency at the scale of the LANDSAT imagery. In this way the original black areas became clear regions, which, when the mask is overlaid to the LANDSAT imagery, permit that portion of the image that lies above the contour value to be viewed.

Although the number of contour masks needed is conditioned by altitude variations of the basin, there is no need to go above the altitude of the permanent snow line. Constructing these masks by hand can be tedious, but they are an integral and vital tool in assessing snow coverage. In instances of partial cloudiness, these masks can establish a snow line, and, assuming that contoured snow line is similar throughout the basin, sometimes an inferred estimate of snow coverage can be obtained

7000 ft or higher

Selected Contour Elevation

FIGURE 29 UPPER SNAKE BASIN, SELECTED CONTOUR ELEVATIONS

8000 ft or higher

FIGURE 29 UPPER SNAKE BASIN, SELECTED CONTOUR ELEVATIONS (Continued)

9000 ft or higher

FIGURE 29 UPPER SNAKE BASIN, SELECTED CONTOUR ELEVATIONS (Continued)

10000 ft or higher

FIGURE 29 UPPER SNAKE BASIN, SELECTED CONTOUR ELEVATIONS (Concluded)

for the total basin. Under these cloudy conditions this could not be accomplished using only radiance thresholding.

At the beginning of the project, digitized topographic maps were assumed available from the Defense Mapping Agency (DMA), and these would have greatly simplified the generation of the contour masks. Unfortunately, repeated attempts to obtain these products were unsuccessful. Currently, the USGS is preparing to edit, copy, and distribute the DMA tapes; hopefully, therefore, contour masks for future programs can be prepared largely by computer processing.

3 Basin Outline Masks

The basin outline masks were generated in the same manner as the elevation-contour masks: all of the region within the basin was blackened so that this area became clear in the photographic negative. The purpose of the basin outline is to overlay the LANDSAT imagery, providing the basin boundary within which the binary products will appear during radiance thresholding.

4 Grid Overlays

This task included constructing drainage patterns and UTM grids as overlays to the LANDSAT imagery, to aid in locating and overlaying the basin area on that imagery. The drainage pattern was taken from USGS maps at 1:250,000 scale, copying major rivers, lakes, and other features identifiable in the satellite imagery. This tracing was photographed, reduced to an appropriate scale (1:1,000,000), and developed as a positive transparency on stable film.

The UTM grid was also taken from the USGS maps and subdivided into 2.5 x 2.5 km grid squares. This, too, was photographed, reduced to appropriate scale, and developed as a positive transparency, usable as

an overlay. The UTM values are an aid in locating scenes or portions of scenes when the display resolution is larger than the TV screen.

B Radiometric Analysis by ESIAC

In the ESIAC, while input can be from tape, the normal data sources are positive film transparencies of LANDSAT imagery. The system scans all or selected portions of these images with a high quality television camera, and has provision for storing several hundred TV frames in precise register on an analog video disc memory. At the same time that the scenes are being viewed as images, the scene radiance data is continuously available in electrical form, ready to be measured or operated on. By scanning and storing the gray-scale calibration step tablets along with the images, an operator can then make radiometric measurements on the images with a relatively high degree of accuracy.

1 Edited Single-Band Thresholding

Clean, well-illuminated snow exhibits radiance that is always greater than the radiance (in the visible region) of other scene constituants found in mountain regions. Thus measurements for a significant portion of the complete snow scene can be extracted by the relatively simple process of recording only those scene elements (pixels) where the brightness or radiance exceeds some specified threshold. This process is illustrated in Figure 30.

A key difference between the SRI mask-making procedure and the reported work of others employing electronic or photographic "density slicing" is that the ESIAC allows the operator, while he is adjusting the threshold, to conveniently compare the thresholded mask continuously and critically with the original scene image in full tonal range and sometimes in color. Nonetheless, repeated tests with numerous mountain snow scenes

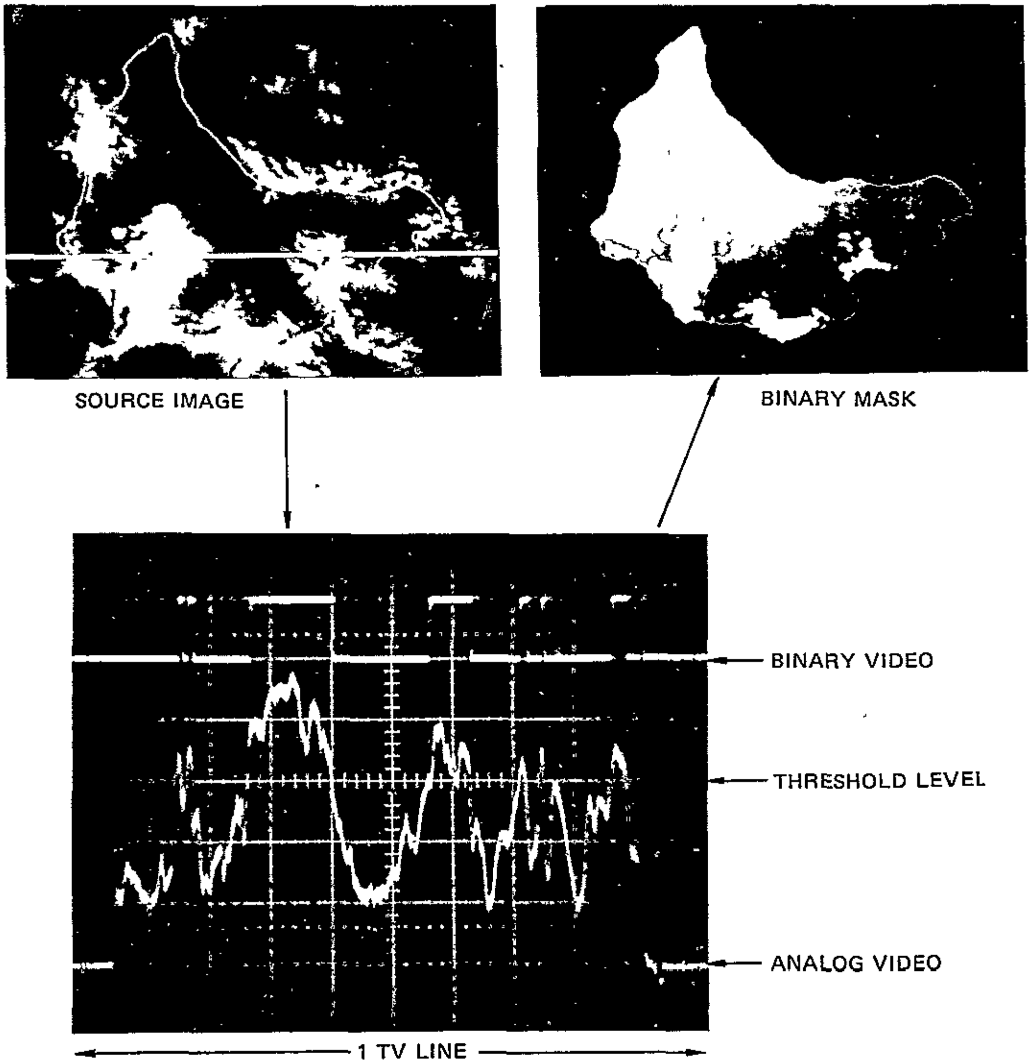


FIGURE 30 EXAMPLE OF CREATION OF BINARY SNOW MASK BY AMPLITUDE THRESHOLDING OF THE ESIAC TV WAVEFORM

Display shown is a small section of the MSS-5 record of ERTS Image 1041-18253 of 2 September 1972. The Thunder Creek Drainage Basin outline has been electronically superimposed. The analog video waveform is for the single horizontal scan line shown intensified in the upper left figure. Note that when the video waveform is above the threshold level (bright portions of image) the binary signal is "high." The binary video is logically combined with a stored binary basin outline map, and then used to generate a binary map (mask) and to control a digital counter which totals the areas-above-threshold within the basin.

and with operator/analysts of different levels of training have shown that a significant percentage of snow is missed by the "first cut" procedure described above. These omissions are owing to low radiance, primarily resulting from shadowing, patchiness, or tree cover.

The mask-making procedure employed for this project employed two additional steps to improve accuracy. First, a revisable "scratch-pad" memory was used to accumulate sections of the mask and permit localized corrections to be made by the operator/analyst. The mask area could be locally biased upward or downward. It would be biased upward (for example, to compensate for poor illumination on north-facing slopes) either by lowering the thresholding level or by actually "painting in" regions believed to be snow covered. Alternatively, the mask area could be locally biased downward (for example, to compensate for obvious image spreading owing to optical flare effects) either by raising the threshold level or by writing small patches of full black and essentially erasing white. In the second step, superimposed elevation contours were used to guide the analyst in making the thematic extractions.

The binary snow mask created by operator/analysts was confined within the basin boundary by performing a logical AND operation between the snow mask and a registered full-basin mask stored in one of the ESIAC memory tracks. The resulting binary product was then stored on another memory track for subsequent photography and digital readout as described in the next section.

Regularly the available imagery provides incomplete coverage of the basin under study. For example, the coverage reference map of Figure 1 shows that whenever the LANDSAT frame center falls west of its "nominal" location (because of cross tracks orbit drift or satellite roll error) the eastern extremities of the Upper Snake basin will not be imaged during the main pass. Only if cloud-free imagery taken from

the adjacent track on the previous day is available can the full snow pack be measured. Data voids owing to partial cloud cover present a similar problem. The linear extrapolation implied in the summary values of Table 6 is obviously only a first approximation. A much preferable procedure would be to substitute "best estimate" snow cover values for those regions where real data is missing. The "inventory by boxes" approach is directed toward the eventual implementation of such a procedure.

2 Measurement of Binary Product

The completed thematic map is composed of TRUE or FALSE (snow or no snow) pixels within the rectangular array approximately 600 cells wide by 500 cells high. The way is then paved for data readout to be accomplished by any method of digital data recording. The choice of method largely depends on the format and detail desired for effective data utilization. The simplest objective procedure is merely to total the number of TRUE pixels, obtaining a measure of the total snow area; the ESIAC is fitted with a counter to provide this value both visually and in a computer-compatible electrical code.

For this project, the mask area was also read out in increments corresponding to 2.5 x 2.5 km segments of ground area. The reasoning behind this particular choice was detailed in the project proposal; basically, it appears to provide a convenient compromise that, within the constraint of a reasonable data storage volume, permits objective comparisons with detailed photointerpretation results and also permits later machine sorting of the data--for example, according to elevation sectors.

For the scale at which the snow scenes were analyzed, each 2.5 x 2.5 km box included 625 TV pixels and each TV view included about 384 boxes, usually in an array 24 wide by 16 high. Thus, significant

data compression was achieved by recording for each box only a single digital number representing the number of tenths of cover within that box. An X was used to indicate a full box or 10/10s coverage.

The mechanics of the readout process evolved through several steps during the course of this project, but all output products generated were in the same display format. For the first basin analyzed, the North Santiam, each snow mask was gated with a square "cursor intersection" patch, 25 pixels wide by 25 pixels high, before being routed to the pixel counter. The cursor box was then manually indexed across the mask, guided by a superimposed 2.5 x 2.5 km grid. For each grid box location, the counter reading was divided by 625, using a hand calculator, and the resulting value for tenths of cover was manually logged onto a data sheet.

By the time of readout for masks of the Boise basin, the box stepping procedure had been automated, and an interface had been established between the ESIAC pixel counter and a nearby PDP-11 computer, so that the computer could perform the time-consuming division and recording processes. For this basin, which could be covered by only four TV views, the final display printouts for the whole basin were assembled by manual paste-ups of the computer printed records for the individual parts.

The last basin to be analyzed was the Upper Snake, which required 11 TV views for full coverage. By this time, a computer program had been written to assemble the component parts into one full-basin map on the PDP-11 output line printer.

Thus, as of the end of the first phase of this project (June 30, 1975), all of the reduced (compartmentalized) snow data on Boise Basin and the Upper Snake Basin for 1973 and 1974 resided in the disc file of the PDP-11, and the ten masks for the North Santiam Basin which were read out by hand, can be typed into the same format in a matter of a very few hours when necessary.

C Measurement Example

Because of the need to make the display resolution of the ESIAC nearly matched to the resolution available from the LANDSAT imagery, the size of the basin may preclude its viewing in a single TV view. As described earlier, eleven TV views were required to cover the largest basin, Upper Snake Basin; four to cover the Boise Basin, and one to cover the smallest, North Santiam Basin; each TV view was considered a basic Part. Therefore, to obtain the total basin coverage of snow in the case of Boise Basin and the Upper Snake Basin it was necessary to obtain snow measurements for each TV view or basin Part and then combine them into a total value of basin snow coverage.* An example of the computer print-out of the snow distribution (in tenths) for a single TV view is shown actual size in Figure 31. The "dots" in the horizontal and vertical axes are representative of 2.5 km distances. (The raised asterisks accent the 10-km divisions.)

The standard Pica spacing of most computer printers (ten characters per inch horizontally and six lines per inch vertically) results in a display with unequal scales in the two directions. With 2.5 x 2.5 km boxes, the horizontal scale turns out to be very nearly 1:1 million, but the vertical scale is stretched by the factor of 10/6. An example illustrating the total basin distribution of snow coverage after combining the computer printouts for various basin parts is given in Figure 32. A photographic montage of the binary product for the basin and day represented in Figure 32 is given in Figure 33.

*For reference, the actual computer printout for all of the component parts are being supplied to the sponsor in a separate, single-copy supplement to this report.

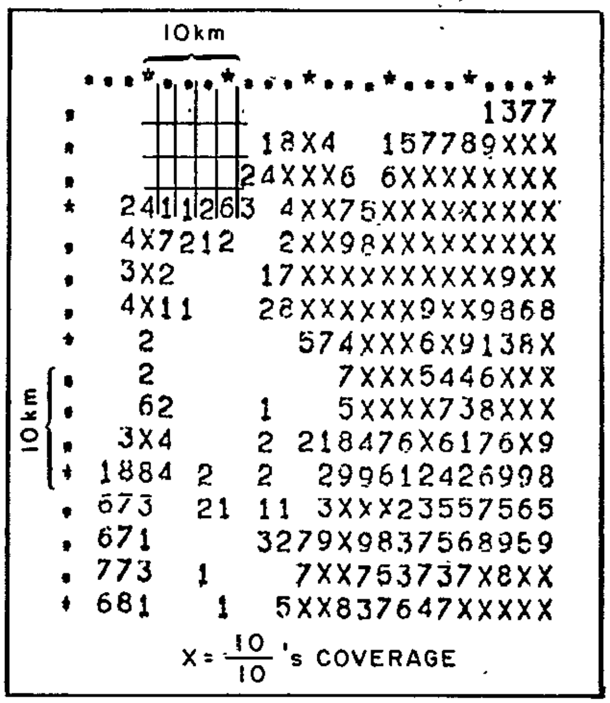


FIGURE 31   EXAMPLE OF COMPUTER PRINTOUT

BASIN: BOISE

DATE (YEAR, MONTH, DAY): 73-4-19

TOTAL BASIN AREA (SQ. KM): 7254.0

BASIN AREA MEASURED (SQ. KM): 7254.0

SNOW AREA (SQ. KM): 4750.4

(PERCENT OF BASIN): 65.5

GRID BOX HEIGHT (KM): 2.5

WIDTH (KM): 2.5

UTM ZONE: 11

UTM COORDINATES OF

UPPER LEFT CORNER,

EASTING (KM): 570

NORTHING (KM): 4885

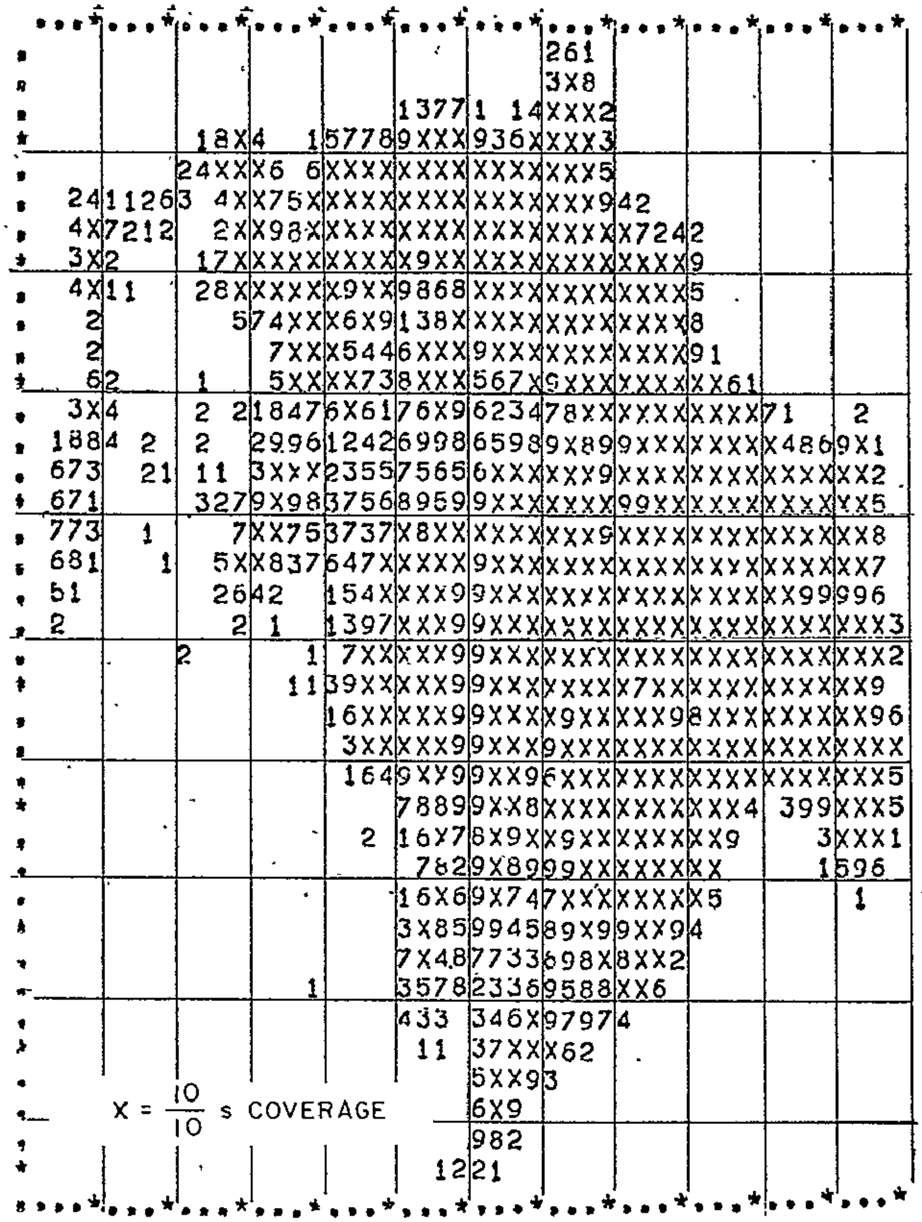


FIGURE 32 EXAMPLE OF COMPUTER PRINTOUT SHOWING DISTRIBUTION OF SNOW COVERAGE (IN TENTHS), BOISE BASIN, PARTS 1-4 COMBINED, 19 APRIL 1973

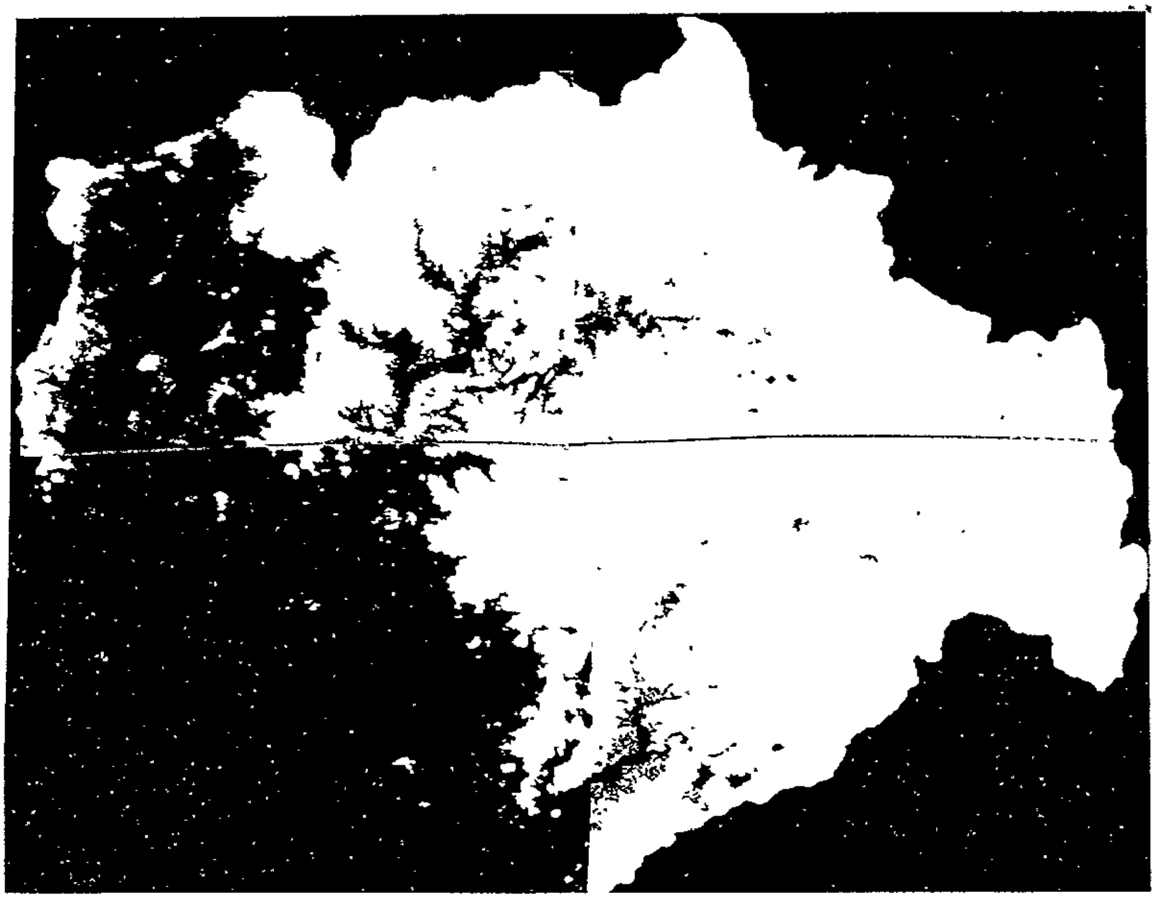


FIGURE 33 MONTAGE OF PHOTOGRAPHS OF BINARY PRODUCTS, BOISE BASIN, PARTS 1-4 COMBINED, APRIL 19, 1973

V REMARKS

As each new satellite snow survey is completed, more information on the complex trade-offs between speed, accuracy, precision, and measurement costs is obtained. As yet, little can be added to what has already been published regarding the accuracy and precision of ESIAC methods.[1] However, the procedure of recording snow cover data by subbasin increments, i.e., "boxes," should be of considerable help in assessing the nature and magnitude of errors in accuracy and precision. Research studies currently underway for Dr. Mark Meier, USGS, in the North Santiam basin are designed to address the problem.

Regarding measurement speed, by the end of this project an average analysis rate of one TV frame per fifteen minutes was being maintained rather consistently when the operator was already familiar with the general characteristics of the basin and the required basin maps contour overlays and reference imagery had previously been prepared and stored in the ESIAC memory. This figure includes time for:

- Registering the new image to a previously stored reference frame.
- A brief study of the scene.
- Creating and editing the mask.
- Bounding by the basin boundary map, and readout of the mask to the computer by 2.5 x 2.5 km boxes.

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[1] Wm. E. Evans, "Progress in Measuring Snow Cover From ERTS Imagery," Proceedings, Western Snow Conference, Anchorage, Alaska, April 1974.

This processing rate of fifteen minutes per TV view will probably remain a realistic characteristic of the present operating procedure. If the analysis were performed from a display of reduced resolution, so that a basin the size of Boise basin could be covered with a single TV view instead of the four used in this study, a corresponding reduction in measurement time would, of course, result. However, until more is learned about the relation between accuracy and resolution, it appears wise to make the fullest possible use of the available LANDSAT resolution.

For the longer term, the best prospects for achieving operational inventories over large areas at tolerable cost undoubtedly will involve automatic or semi-automatic processing of the full-resolution data. What we learn now through ESIAC processing at near-full resolution will contribute directly to the development of efficient algorithms for more complete machine processing.

Appendix

ESIAC

ELECTRONIC SATELLITE IMAGE ANALYSIS CONSOLE

SRI STANFORD RESEARCH INSTITUTE • Menlo Park, California 94025 • U.S.A.

Features

- Time-lapse display of multispectral imagery.
- Input from TV scan or digital tape.
- Magnetic disc storage of 600 TV frames.
- Quantitative measurements of displacements, areas, radiances, and multispectral band ratios for specified scene constituants.
- Binary thematic maps based on monoband or multispectral decisions.
- High interactivity (designed for hands-on use by scientific investigators).
- Tolerable operating cost.

Sample Applications

- Measurement of extent of snow cover.
- Evaluation of simultaneous visual and thermal IR imagery (meteorological, air pollution, and hydrologic uses).
- Cloud motion measurement.
- Enhancement of subtle geologic patterns by visual integration during time-lapse sequences.
- Rapid scaling, positioning, stretching, and contrast manipulation for overlaying imagery from different sources.

General Description

The ESIAC (Electronic Satellite Image Analysis Console) utilizes television scanning, storage, editing, and animation techniques to facilitate rapid qualitative and quantitative analysis of satellite imagery.

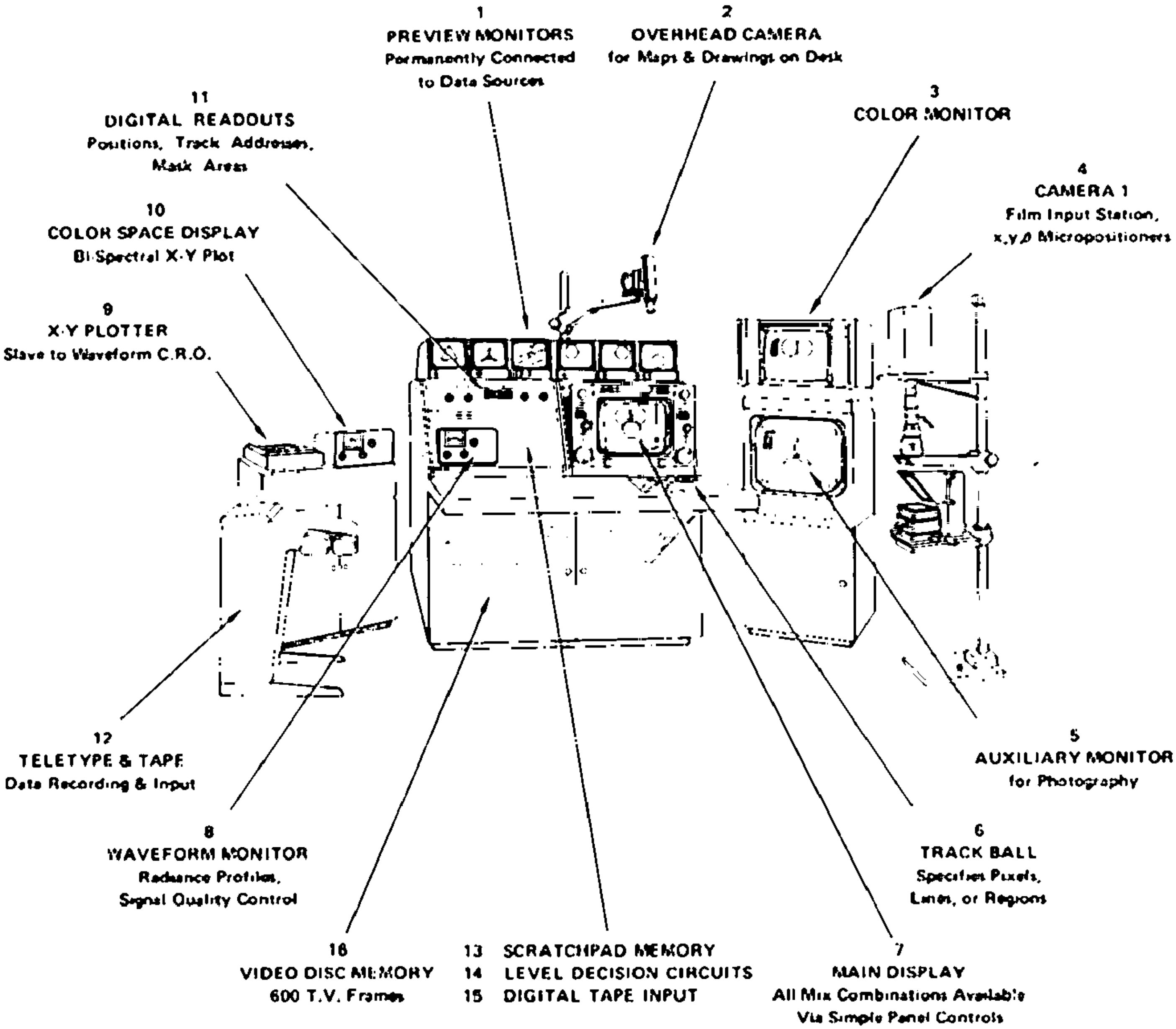
The principal feature is the ability to exploit the temporal dimension of repetitive satellite coverage, as provided by ERTS or SMS. This is typically accomplished via time-lapse presentations, but many of the functions required for time-lapse are equally useful in performing a wide variety of image comparisons, such as relating scenes to maps, to thematic extractions, and to other views of the same scene. Numbers in parentheses in the following description refer to callouts on Figure A-1, which shows the equipment configuration.

Normal input is via film transparencies that are scanned by a quality vidicon camera (4). Zoom optics and an extensive system of micropositioners permit scaling of the image and precise registration to scenes or sequences already stored in memory. Images are stored on an analog video disc memory, which has a capacity of 600 full TV frames, often handled in pairs to provide 300 bi-spectral frame pairs. Frames can be assessed sequentially in milliseconds, or randomly in seconds. A fast digital-to-analog interface and cable link to a nearby computer provide a means for loading the disc memory with raw or processed images derived from digital tape.

Storage and handling of the images as TV signals permits quantitative measurements to be made with useful precision at a small fraction of the time and cost required for a fully digital system of comparable versatility. Measurements and logic decisions can be made on radiance data pertaining to any region of the scene while it is being viewed as an image.

An array of small preview monitors (1) continuously displays the contents of the major data sources. The operator can use simple switching and mixing controls to merge positive or negative amounts of imagery from the data sources into a composite image on the main viewing screen (7). Alternatively, the operator can rapidly switch the display between any two data sources to provide flicker comparisons--a very powerful procedure for accentuating small differences. He can also cycle through stored image sequences to generate a time-lapse display and can adjust the animation timing to keep time with mental assimilation.

The color display (3) greatly magnifies the possibilities for data presentation. While complete flexibility is provided for programming signals to all three guns of the color CRT, in practice, it is often desirable to limit the possible combinations in order to avoid confusion.



NOTE: Numbers keyed to descriptions in text

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FIGURE A-1 ESIAC EQUIPMENT CONFIGURATION

An arrangement that has been found applicable to a wide variety of multispectral applications has been to operate with a two-primary system. Visible band images are stored on the "A" side of the memory disc (tracks A0 through A300) and are displayed in Cyan (green plus blue). Concurrent infrared images are stored on the "B" side of the disc (tracks B0 through B300) and are displayed in red. Since the moving record/reproduce heads on both sides of the disc can be stepped simultaneously, bi-spectral time-lapse presentation is then possible.

Additional Functions

Overhead Camera (2)--An auxiliary vidicon camera fitted with zoom optics is suspended over the horizontal worksurface. While it can be used for hard copy data entry, its more usual function is to achieve temporary superposition of maps on the displayed image for orientation. Equally useful is its function in output recording. Line drawings sketched on a notebook page or other paper located on the desktop appear merged with the display image without paralax, and features too subtle to photograph well can be documented by hand drawing directly on the paper.

Auxiliary Monitor (5)--The 17-inch monochrome display can be connected in parallel with any of the other displays to facilitate photographic data taking. It is also often used to hold a reference picture for side-by-side comparison to other displays.

Track Ball (6)--The operator controls the position and size of the digitally-derived measuring cursor by means of this device. The cursor can be made to appear in several forms (cross, dot, box, box outline) and is used to measure linear displacements. It can also be used to specify individual pixels or rectangular pixel groups within the image for measurement, rerecording, or other special consideration. The cursor location can be intensified on any or all monitors to help in coordinating the displayed data.

Waveform Monitor (8)--A dual-channel oscilloscope is used to display video signal amplitude versus time for various level setting and supervisory needs. When triggered in time coincidence with the cursor, this display can function as a microdensitometer to provide a radiance profile along any specified scan line or portion thereof.

X-Y Plotter (9)--A pen-and-ink plotter is connected to the Waveform Monitor oscilloscope via a sampling interface unit. It permits large, sharp, hard copy records to be made of radiance profiles or any other repetitive waveform displayed on the oscilloscope. For some applications, the method provides an attractive alternative to photographing the CRO screen.

Color Space Display (10)--This display generates a two-dimensional scatter diagram depicting the distribution of radiances in any two spectral bands for the entire image or selected portions of it. In a typical application, vertical (y axis) displacements are caused to be proportional to infrared radiances at the same time that horizontal (x axis) displacements are made proportional to radiances in a visible band. For imagery such as ERTS, where reference gray scales are available on the film, a unique data entry procedure permits radiometric calibration tics to be added to define both axes and the 45° diagonal. The two-dimensional color coordinates of any pixel or small group of pixels (as specified by the cursor intersection in the main image display) can be read directly from this graphic presentation in units linearly correctable to absolute radiance values for the scene.

A summary impression of the spectral statistics for an entire image can be obtained by observing the brightness distribution over the diagram. Scenes containing significant areas of snow or clouds, for example, produce color maps showing appreciable energy distributed along the "neutral" diagonal. A heavily vegetated scene, on the other hand, will generate a scatter diagram with most of its energy above and to the left of the diagonal. Water bodies normally map into the lower right region. Regions of the color space display can be selectively intensified to show the spectral criteria associated with a thematic extraction map. Thus, the display is of immense help in adjusting the various ratioing and thresholding controls needed to generate such extractions [see also description of item (14)].

Digital Readouts (11)--Numerical displays are provided for cursor location, disc addresses, and area measurements (white pixel count within a thematic mask). Upon command, these readings can be recorded via teletype and paper tape (12).

Scratchpad Memory (13)--One full frame of digital image storage is provided in addition to the storage provided on the magnetic video disc. This fully addressable memory stores an array of 520 lines × 400 elements

× one bit. Thus, it has no gray-scale capability, but is used principally for temporary storage and editing of line-type overlays and binary thematic masks. Masks created objectively by machine processing of the image data can be revised or "cleaned up" by the analyst-operator using light pen or cursor control. This memory is also useful in storing "keying" or control masks required when measurements are to be confined within some irregularly shaped area, a drainage basin for example.

Level Decision Circuits (14)--Four of these LDCs are provided. Each is a fast-one-bit analog-to-digital converter with a manually adjustable decision threshold. They are used to generate binary thematic masks in accordance with simple mathematical operations on the input video waveforms. The binary outputs can be combined logically to create a mask that is, for example, white or TRUE for all regions of the image where the visible band radiance is greater than X percent of full scale and the infrared radiance is between Y and Z percent of full scale. The LDCs can also be used to create masks based on ratios of responses from two different spectral bands.

Digital Tape Input (15)--An interface unit, and associated cabling, is provided to permit loading the disc memory with image data from digital tapes handled by a nearby PDP-11 computer facility. Loading of a complete TV image can be accomplished in a minimum of 17 seconds. While image manipulation during the data transfer is limited to simple scaling and x-y translation functions currently, any desired amount of digital preprocessing can be performed in separate operations prior to the transfer.

GENERAL PERFORMANCE SPECIFICATIONS

Scanning standards	Broadcast TV; 525 lines/frame, 30 frames/second, 2:1 interlace
Video disc storage capacity	16-in. magnetic disc, two movable heads, each covering 300 tracks (TV frames), plus one fixed head for synchronization
Display horizontal resolution	Approximately 350 picture elements per picture width, limited by the video disc memory bandwidth of 4 MHz
Cursor resolution	660 steps horizontally and 490 steps vertically (for unblanked portion of raster)
Gray scale capability	Determined chiefly by the signal-to-noise ratio obtainable from the video recorder (specified at 40 dB). With care, all ten steps of the gray scale on the standard TV test pattern can be resolved.
Picture slewing rate	Variable: 0 to 15 frames/second either direction
Data sources Positive or negative amounts of any form can be mixed simultaneously on the main monitor	Camera 1 (local) Camera 2 (remote) Camera 3 (overhead) A disc output B disc output Thematic mask Scratchpad memory Cursor Rectangular grid
Positioning repeatability for source transparencies (film)	Less than ±0.001 in.
Field coverage of camera 1	Continuous zoom over 10:1 range. Range is shiftable by means of various auxiliary lenses. Typical coverage range used for ERTS 70 mm transparencies: Max zoom--9.3 × 5.5 mm; Min zoom--72 × 54 mm; Illuminated light table--103 × 80 mm; Hard copy--up to several feet.
Solid state "scratchpad" memory capacity	520 TV lines at 400 bits/line
Digital computer interface	6400 bit Buffer Memory (8 bits/pixel, 800 pixels/TV line) Output Rate, 12.6 × 10^6 pixels/sec. Input Rate, limited by connected computer and/or tape. For PDP-11, maximum transfer rate is one TV line/disc revolution, 16.3 sec/frame